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Fair DSL-LTE Dynamic Spectrum Design Based-Utility Functions on Multiple Quality of Service Network

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Abstract

The purpose of this research is to formulate a C-RAN(Cloud-Radio Access Network) model based on a fair network combined with an isoelastic utility function and a modified cobb-douglas utility function and then optimize the consumer problem on bandwidth consumption by dividing the financing scheme into three, namely flat-fee, usage-based, and two-part tariff. This research uses traffic data containing inbound and outbound data with two split time which are in off-peak and on-peak hours. The data is obtained through one of the local server in Palembang. Previous research informed that the C-RAN model get optimal benefit if Internet Service Provider (ISP) applies it. The improvement of the model is to be conducted using two utility function to seek for improved solutions. The new proposed model has best solution that has been improved using an isoelastic utility function of flat-fee financing type with an objective value obtained of 1.83333 with 17 iterations. It can be concluded that new designed model can achieve better results rather than old version involving C-RAN model.

Keywords: C-RAN, fair network, modified cobb-douglas, isoelastic

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1. Introduction

The internet at this time is a necessity that cannot be separated from human life. The internet can provide benefits in various fields of life, both in the social, cultural, economic, health, political and educational fields. Humans around the world can communicate through an electronic network because of the connectivity of a computer network known as the internet (Rustam, 2017).

Internet users are increasing every year resulting in internet service providers (ISP) as internet service providers must be able to provide better quality of service or Quality of Service (QoS) at an efficient cost (Rosston & Wallsten, 2020). QoS is a method used to measure how well a network service (Audah et al., 2017; Jain et al., 2018; Pamungkas & Pramono, 2018). Bandwidth can be used optimally with the presence of QoS so that it can improve the quality of internet services received by users (Armanto & Daulay, 2020; Merayo et al., 2016; Saint & Brown, 2019). According to Wu & Banker (2010), there are three internet financing schemes to maximize the level of user satisfaction with the ISP. The internet financing schemes are flat-fee, usage-based and two-part tariff(Indrawati et al., 2021; Puspita et al., 2021). The utility function relates to the level of satisfaction obtained by service users for the consumption of the services they obtain, so that the ISP can maximize profits to achieve the goal. (Indrawati et al., 2017).

This study uses an isoelastic utility function and a modified Cobb-Douglas utility function. Transformed Cobb-Douglas utility function not only simplifies but also makes it possible to examine consumer influences on the firm's price choice structure (Wu & Banker, 2010). The Isoelastic utility function is used to maximize profits and reduce the risk of loss to

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consumers. In addition, the selection of the two utility functions is also due to the fact that the two utility functions are still rarely discussed in the Dynamic Spectrum Management (DSM) model research(Alshaflut & Thayananthan, 2018; Saint & Brown, 2019). DSM has been proposed and recognized as an effective approach to reduce the problem of spectrum scarcity. In DSM users known as secondary users can access the primary user spectrum if the primary user spectrum is not used (Liang, 2020). DSM serves to reduce the effects of crosstalk that leads to the best performance by allowing radios to share multiple frequencies without causing interference. (Nidhi *et al*., 2021).

In the previous study discussed by Indrawati *et al*., (2017) and Puspita *et al*., (2020) a dynamic approach based on QoS to model Traffic Management (TrM) with a C-RAN-based optimization approach that can improve network performance was proposed. This research, then discuss the C-RAN network scheme and formulate a new model plan that involves fair network traffic management and utility functions. Previous research discussed by Indrawati *et al*, (2017) and Puspita *et al*., (2020) does not use the utility function whereas in the development of DSM on C-RAN the utility function plays an important role in measuring consumer satisfaction. For this reason, it is necessary to design a DSM model that involves fair network traffic management (Dönmez et al., 2022; Xi et al., 2019) and utility functions.

2. Method

The Steps taken to conduct research are as follows:

a) Describe the data

This research uses data which is traffic data and is divided into inbound and outbound data. The data is generated from a local server in Palembang. The data comprises with 2 sessions, namely data during crowded and uncrowded hours. Data during high traffic hours starts at 07.00-18.59 West Indonesian Time while data during non-crowded hours starts at 19.00–06.59 WIB.

b) Specify the parameters and design variables used.

c) Conduct formulation model *improved* C-RAN by transforming the C-RAN model, fair network and modified cobb-douglas and isoelastic utility function

d) Determine the optimal solution by completing the model in steps 3 using LINGO 13.0.

e) Compare the optimal solutions between C-RAN models; C-RAN model and fair network; C-RAN model, fair network, and modified cobb-douglas utility function; and C-RAN model, fair network, and isoelastic utility function.

3. Result and Analysis

3.1. Description Data

The data used is internet usage traffic data. Internet usage data is divided into incoming data and outgoing data. Internet usage data will then be divided into traffic data busy hours and traffic data non-busy hours as Table 1 explained.

3.2. Formulation of Indicator and Variables

In order to obtain good results, modifications are needed for the model. Based on this, 2 case models are used, namely:

a. D_0 is constant and Q^M is variable.

b. D_0 and Q^M are constants.

Based on these two cases, parameters were obtained for each case as Tabel 2-3 Indicated. Table 4 and 5 displays the design variables.

Table 1. Traffic Data Usage for Busy Hours and Non-Busy Hours

Usage Rate	Usage (bit)	Usage (byte)	Usage (*kbps*)
$\bar{B} = \bar{B}_1$	207,961,263.3	25,995,157.9	25,385.9
$\bar{B}_2$	158,625,911.6	19,828,239.0	19,363.5
B_m	23,859,694.49	2.982,461.81	2,912.5
$\bar{C} = \bar{C}_1$	139,856,855	17,482.107	17,072
$\bar{C}_2$	138,358,834.8	17,294,854.3	16,889.5
C_m	9,607,691.867	1,200,961.483	1,172.814

Table 2. Original C-RAN Model Parameters

For C-RAN Model – *Fair Network*	
D_0	: Defined bandwidth by ISP
ϑ_{eff}	: Price of bandwidth
Q_c^R	: Bandwidth consumed during busy hours
Q_{bh}	: Bandwidth consumed during non-busy hours
τ_R	: upper limit of QoS
τ_{ER}	: lower limit of QoS
η_0	: Max limit of a user's bandwidth consumed
Q_{max}^R	: Max bandwidth allocated
k_j^R	: Max and min amount of bandwidth consumed
$l_{j,d}^R$	: Number of bandwidth consumption per day (kbps)
T_n^{min}	: Minimum throughput received by users

Table 3. Additional Parameters for Improved Models

Additional Indicator for Improved Models	
H	: Cost to join the service
H_B	: Price set in busy hours
H_C	: Price set in non-busy hours
$U_{(B,C)}$	: Utility functions of consumer for usage rates during hours.

Table 4. Variable for *Improved* C-RAN Model

Variable for C-RAN Model – *Fair Network*	
$p_{j,d}$	: The allocation indicator Resource Block (RB) has a value of 0 or 1.
$q_{j,d}$	: RB bandwidth allocated to RUE
k_d^{R2M}	: Loss of suitable path
l_d^{R2M}	: Corresponding channel
Q^M	: Starting bandwidth consumed
k_j^M	: RB to RUE line loss
$l_{j,d}^M$	: Channel profit
S_0	: Bandwidth consumed when no hosting
z_n	: Total bandwidth received by consumers

Table 5. New Additional variables for Improved Models

Additional variables for Improved Models		
$\overline{B}$	:	Maximum usage rate of consumers from the service in busy hours
$\bar{C}$	:	Maximum usage rate of consumers from the service in non-busy hours
B	:	Usage rate of service in busy hours
C	:	Usage rate of service in non-busy hours
Z_i	:	"1" if consumer join the program and "0" if consumer doesn't join

Table 6-8 show the value of parameter needed for the improved model.

Table 6. Indicator Values in Traffic Data

Indicator	Value (*kbps*)
$k_1^M = \bar{B}_1$	25.385,9
$k_2^M = \bar{B}_2$	19.363,5
$k_3^M = B_m$	2.912,5
$k_4^M = \bar{C}_1$	17.072
$k_5^M = \bar{C}_2$	16.889,5
$k_6^M = C_m$	1.172,814
l_{11}^M	17.597,87
l_{12}^M	12.455,13
l_{21}^M	11.041,31
l_{22}^M	21.689,19
l_{31}^M	28.307,54
l_{32}^M	17.178,63
l_{41}^M	21.867,22
l_{42}^M	18.238,77
l_{51}^M	40.214,33
l_{52}^M	20.177,96
l_{52}^M	13.923,58
l_{52}^M	22.836,62
l_{13}^M	29.145,26
l_{23}^M	14.971,25
l_{33}^M	12.931,33
l_{44}^M	18.060,24
l_{45}^M	14.619,94
l_{46}^M	13.853,07
l_{54}^M	17.024,73

Indicator	Value (*kbps*)
l_{55}^{M}	25.563,17
l_{56}^{M}	24.683,44
l_{64}^{M}	20.252,07
l_{65}^{M}	20.451,66
l_{66}^{M}	28.309,62

Table 7. Indicator Values on the Original C-RAN Model

Indicator	Value (*kbps*)
Bandwidth (D_0)	5.000
Power amplifier efficiency (ϑ_{eff})	500
Bandwidth of the circuit (Q_c^R)	4.500
Bandwidth consumed from the fronthaul link (Q_{bh})	4.000
Upper limit QoS (τ_R)	128
Lower limit QoS (τ_{ER})	64
Predetermined limit (η_0)	4.500
Max displacement bandwidth (Q_{max}^R)	q
Initial bandwidth usage (Q^M)	150

Table 8. Value of Parameters Used in Financing Schemes

Parameter	Financing Schemes		
	Fixed Costs	Based on Use	Two Part Rate
a	4	4	4
b	3	3	3
$\bar{B}$	25.385,9	25.385,9	25.385,9
$\bar{C}$	17.072	17.072	17.072

3.3. Development of Improved C-RAN Model

After formulating parameters and variables, then develop improved C-RAN model. The model is obtained by combining the C-RAN model with the fair network model and then adding utility functions and QoS .

$$\max \frac{\sum_{j=1}^{J+G}\sum_{d=1}^{D} p_{j,d} D_0 \log_2\left(1+\partial_{j,d} q_{j,d}\right)+\left(\sum_{n=1}^{N} z_n\right)^2}{\vartheta_{eff}\sum_{j=1}^{J+G}\sum_{d=1}^{D} p_{j,d} q_{j,d} + Q_c^R + Q_{bh} + I\sum_{n=1}^{N} {z_n}^2} + U_{(S,T)} - Q_S S - Q_T T - QZ_i \tag{1}$$

Subject to:

$$\sum_{j=1}^{J+G}\sum_{d=1}^{D} p_{j,d} = 1, p_{j,d} \in \{0,1\} \tag{1.1}$$

$$\sum_{j=1}^{J} L_{j,d} \geq \tau_R, d \in \Omega_1 \tag{1.2}$$

$$\sum_{j=J+1}^{J+G} L_{j,d} \geq \tau_{ER}, d \in \Omega_2 \tag{1.3}$$

$$\sum_{j=J}^{J+G} p_{j,d} q_{j,d} k_d^{R2M} l_d^{R2M} \leq \eta_0, d \in \Omega_{II} \tag{1.4}$$

$$\sum_{j=1}^{J+G} \sum_{d=1}^{D} p_{j,d} q_{j,d} \leq Q_{\max}^R, q_{j,d} \geq 0 \tag{1.5}$$

$$z_n \geq T_n^{\min} \tag{1.6}$$

$$S \leq \bar{B} Z_i \tag{1.7}$$

$$T \leq \bar{C} Z_i \tag{1.8}$$

$$U_{(B,C)} - H_B B - H_C C - HZ_i, Z_i = 0 \text{ atau } 1 \tag{1.9}$$

where:

$$L_{j,d} = p_{j,d} D_0 \log_2(1 + \partial_{j,d} q_{j,d}) \tag{1.10}$$

$$\partial_{j,d} = \begin{cases} \dfrac{k_j^R l_{j,d}^R}{D_0 S_0}, & d \in \Omega_1 \\ \dfrac{k_j^R l_{j,d}^R}{(Q^M k_j^M l_{j,d}^M + D_0 S_0}, & d \in \Omega_2 \end{cases} \tag{1.11}$$

$$U_{(B,C)} = a \log(B+1) + b \log(C+1) \tag{1.12}$$

$$U_{(B,C)} = \frac{B^{1-a}-1}{1-a} + \frac{C^{1-b}-1}{1-b} \tag{1.13}$$

3.4. Internet Financing Scheme Model Based on Data Usage

Based on Equation (1) to Constraint (1.13), the number of RUE usage against RRH selected as much as 3 RUE. The use of RUE against RB is selected as much as 3 RUE. RB usage is selected as many as 2 servers. The number of selected users is 3 users. In this study, J=3, G=3, D=2 was chosen.

because:

$\Omega_1 = \{1, \ldots, J\}$;
$\Omega_2 = \{J+1, \ldots, J+G\}$;

$$\Omega_1 = \{1, \ldots, 3\}$$
$$\Omega_2 = \{4, \ldots, 6\}$$
$$\Omega_{II} = \Omega_1 \cup \Omega_2 = \{1, \ldots, 6\}$$

with:
Ω_1 is allocation RUE to the upper boundary for QoS
Ω_2 is allocation RUE to the lower boundary for QoS
Ω_{II} is allocation RUE to RB

3.5. Internet Financing Scheme Model Based on Data Usage on Traffic Data Using the Modified Cobb-Douglas Utility Function

Through the traffic data obtained from Table 6 and the parameter values in Tables 7 and 8, a modified internet financing schema model can be built into 2 cases with first use and amount of bandwidth usage.

3.5.1. Case 1 (D_0 as constant and Q^M as variable)

The model used for Case 1 uses the model in Equation (1). In this case, the determination of bandwidth follows the provisions of the ISP, namely by combining the equation of the modified cobb-douglas utility function with the model for the consumer. Furthermore, a model is created by substituting the parameter values in Tables 6 and 7. The model is made based on the objective function in Equation (1) with Constraints (1.1) to Constraints (1.11) and Constraints (1.12) the model then solved using LINGO 13.0 so that an optimal solution is obtained.

3.5.2. Case 2 (D_0 and Q^M as constant)

The model used for Case 2 is the same as that used in Case 1, but in Case 2 K_0 and V^M are constants so that by adding the value of V^M to LINGO 13.0, the optimal solution can be obtained.

3.6. Traffic Data-Based Internet Financing Scheme Model Using Isoelastic Utility Function

The modified internet financing scheme model then are split into 2 cases with predefined begining and bandwidth usage and usage.

3.6.1. Case 1 (D_0 as constant and Q^M as variabel)

The model used for Case 1 uses the model in Equation (1). The model is made based on the objective function in Equation (1) with Constraints (1.1) to Constraints (1.11) and Constraints (1.13). Solving the model obtained using LINGO 13.0 so that the solution optimal is obtained.

3.6.2. Case 2 (D_0 and Q^M as constant)

The model used for Case 2 is the same as that used in Case 1, but in Case 2 K_0 and V^M are constants so that by adding the value of V^M to LINGO 13.0, the solution optimal can be obtained.

3.7. Internet Financing Scheme Model Solution

Table 9 shows solution optimal the model of C-RAN using traffic data for Case 1 and Case 2. Furthermore, Table 10 shows the optimal solution of the C-RAN model and the fair network. Table 11 and Table 12 show the optimal solution of the internet financing scheme based on the current research model, namely the C-RAN model, fair network and combined with the transformed Cobb-Douglas utility function in Table 11 and the isoelastic utility function in Table 12.

Table 9. Optimal Solution of original C-RAN Model

Status	**Value**	
	Original Model	
	Case 1	**Case 2**
Type	MINLP	MINLP
Condition	Local Optimally	Local Optimal
Objective	0.0211043	0.0211043
No of Iteration	22	22
	Extension Status	
GMU (K)	65	65
ER (Sec)	1	0

Table 10. Optimal Solutions of C-RAN Model and Fair Network

Status	Value	
	Original Model	
	Case 1	Case 2
Type	MINLP	MINLP
Situation	Local Optimal	Local Optimal
Objective	1	1
Ineligibility	0	0
Repetition	20	20
Separation Extension Status		
Good Goal	1	1
Action	0	0
Renewal Distance	2	2
GMU (K)	66	66
ER (Sec)	0	1

Table 11. Optimal Solutions of C-RAN Models, Fair Network and Transformed Cobb-Douglas Utility Functions

Status	Financing Scheme					
	Flat Fee		Usage		Two Part Tariff	
	I	II	I	II	I	II
Steps	NLP	NLP	NLP	NLP	NLP	NLP
Update Interval	Locally Optimal	Locally Optimal	Locally Optimal	Locally Optimal	Locally Optimal	Locally Optimal
GMU (K)	2	2	2	2	2	2
ER (Sec)	71	71	72	72	72	72
Steps	0	0	0	0	0	0

Table 12. Optimal Solutions of C-RAN Models, Fair Network and Isoelastic Utility Functions

Status	Financing Scheme					
	Flat Fee		Usage		Two Part Tariff	
	Illustration I	Illustration II	Illustration I	Illustration II	Illustration I	Illustration II
Class	NLP	NLP	NLP	NLP	NLP	NLP
State	Locally Optimal	Locally Optimal	Locally Optimal	Locally Optimal	Locally Optimal	Locally Optimal
GMU (K)	1.83333	1.83333	1.83333	1.83333	1.83333	1.83333
ER (Sec)	0	0	0	0	0	0
Iterations	17	17	35	35	41	41

3.8. Comparison of Optimal Solutions Internet Financing Scheme Model

The following is shown the optimal solution of the internet financing scheme model as in Table 13 obtained from Subsection 3.7.

Table 13. Comparison of Optimal Solutions Internet Financing Scheme Model

Model	Financing Scheme	Case	Solver Status					
			Type	Situation	Objective	IIneligibility	Repetition	GMU
C-RAN	-	Case I	MINLP	Locally Optimal	0.0211043	0	22	65
		Case II	MINLP	Locally Optimal	0.0211043	0	22	65
C-RAN and Fair Network	-	Case I	MINLP	Locally Optimal	1	0	20	66
		Case II	MINLP	Locally Optimal	1	0	20	66
C-RAN, Fair Network and Modified Cobb-Douglas Utility Function	Fixed Costs	Case I	NLP	Locally Optimal	1	0	16	71
		Case II	NLP	Locally Optimal	1	0	16	71
	Based on Use	Case I	NLP	Locally Optimal	1	0	19	72
		Case II	NLP	Locally Optimal	1	0	19	72
	Two part rate	Case I	NLP	Locally Optimal	1	0	19	72
		Case II	NLP	Locally Optimal	1	0	19	72
C-RAN, Fair Network and Isoelastic Utility Function	Fixed Costs	Case I	NLP	Locally Optimal	1.83333	0	17	71
		Case II	NLP	Locally Optimal	1.83333	0	17	71
	Based on Use	Case I	NLP	Locally Optimal	1.8333	0	35	71
		Case II	NLP	Locally Optimal	1.8333	0	35	72
	Two part rate	Case I	NLP	Locally Optimal	1.8333	0	41	72
		Case II	NLP	Locally Optimal	1.8333	0	41	72

Table 13 shows the comparison results of the original model of C-RAN; then with fair network; then with transformed cobb-douglas utility function and isoelastic utility function. It is found that the C-RAN model, fair network and isoelastic utility function with flat-fee financing type of Rp. 1.8333/kbps can be solved in 17 iterations.

4. Conclusion

The precise decision is from by improving C-RAN model with isoelastic utility function using flat-fee financing cost and the value 1.83333 with 17 iterations. From the comparison of the optimal solutions, the C-RAN model, fair network and isoelastic utility function were more optimal than the C-RAN model; the C-RAN model and fair network; and the enhanced C-RAN model, fair network and cobb-douglas utility function. This is seen from the larger objective value of the compared model for each case. For further investigation, it is necessary to conduct sensitivity analysis to measure the change in objective function values.

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