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Mathematical Model of Traffic Management-Perfect Substitute-Selfish User Scheme

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Abstract— **Cloud Radio Access Network (C-RAN) is a radio access network centralized with the tools used and related to an antenna in the form of a cellular network that processes the signal and then shares it with the core network or antenna tower belonging to the radio. This research aims to create a C-RAN Model-Selfish User-Perfect Substitute utility function to the internet pricing scheme and then conduct further sensitivity analysis to determine changes in parameters that generate profits. This research is categorized as a Mixed Integer Nonlinear Programming problem by determining the starting bandwidth consumption, divided into 4 cases as the previous extended version, Flat-Fee, Usage-Based, and Two-Part Tariff. This research applies Sisfo Traffic data obtained from a local server in Palembang. This data is useful for validating the model designed. The model is solved to obtain the optimal solution, and sensitivity analysis assesses parameter changes using LINGO 13.0 software. Based on this analysis, an improved C-RAN Selfish User model of the Perfect Substitute Utility function produces the optimal solution, mapping from remote radio head (RRH) to resource block (RB). The bandwidth transmission variable from RB to Remote User Equipment (RUE) has an infinite value. It means that the changes in the value can be set to infinity without affecting the objective function value. The increments and decrements can vary between values 0 or infinity, after which the increments and decrements remain unchanged.**

Keywords— C-RAN, Selfish User, Sensitivity Analysis, LINGO 13.0, Optimal Solution

I. Introduction

The Cloud Radio Access Network (C-RAN) model [1]-[2] is one of the emerging sciences in the field of information service technology that supports 2G, 3G, and 4G [3] and future wireless communication standards. C-RAN is a radio access network that adapts to the equipment connected to the cellular antenna to process the signal and then deliver it to the core network or radio antenna tower [2]. Some of the advantages of C-RAN are that it can increase the use of network capacity, reduce latency or the time it takes for data to move within a network, reduce network intensity, and provide good service quality to users with various applications [4]-[5]. Model validation on C-RAN is carried out with an analytical process, namely sensitivity analysis [6]- [7]. Sensitivity analysis is an analytical process that aims to determine the optimal change level in each variable contained in the function by obtaining information related to new solutions with minimum additional calculations [8]-[9]. The sensitivity analysis results can be identified as the most critical criterion.

This study refers to the model and results of research that has been done previously by Indrawati et al. [4], the preparation of the C-RAN Selfish User Model, which not only focuses on internet financing for users but also measures the level of user satisfaction with internet services [10]–[12]. According to Puspita et al. [1], improving the C-RAN Selfish User Model was developed by considering the utility function and financing schemes that focus on user satisfaction by paying attention to internet financing schemes. The model in this study is a development of the previous model [4], [13]–[15], namely the C-RAN Selfish User Model using the Perfect Substitute utility function with three financing schemes of flat-fee, usage-based, two-part tariff [16]–[18]. The Perfect Substitute utility function [19] was chosen in this study because ISPs have more options to set a price scheme that can attract users to join the financing scheme.

The improved C-RAN Selfish User model needs to be developed by considering utility functions and financing schemes and expanding the number of servers used. The development in this research uses servers on the selected RB [20], as many as three servers. The developed model can prove that the selected utility function can generate maximum profit for the Internet Service Provider (ISP) [21] and validate the model by performing sensitivity analysis to measure changes in the coefficient of the objective function.

II. Research Method

The completion steps carried out in this research :

1. Describe Traffic Sisfo's local server data for 28 days starting from February 01 to February 28, 2022, the data is secondary data grouped at peak hours (07.00 AM-05.00 PM) and off-peak hours (05.01 PM-06.59 AM), which consists of incoming data (inbound) and outgoing data (outbound).
2. Determine the parameters and decision variables used in the C-RAN Model, Selfish User in the objective function, based on the Perfect Substitute utility function.
3. Design the C-RAN Model, based on the Perfect Substitute utility function, by adding three financing schemes flat-fee, usage-based, and two-part tariffs.

4. Determine the optimal solution results and analyze the results obtained.
5. Compare the optimal solution results from the original C-RAN Model, the C-RAN Selfish User Model, and the C-RAN Selfish User Model based on the Perfect Substitute utility function with three financing schemes of flat-fee, usage-based and two-part tariff.

III. Result and Discussion

In this study, secondary data is obtained from one of the local servers in Palembang, namely the Sriwijaya State Polytechnic. The data retrieval process is carried out within one month, starting February 1, 2022, to February 28, 2022. The data uses Traffic Sisfo data, the amount of bandwidth usage when accessing the internet.

The data is divided into two components, namely incoming or Inbound data and outgoing or Outbound data, both of which are expressed in units of bits per second. The amount of data transfer usage grouped into peak hours is calculated based on usage from 07.00 AM to 05.00 PM. In comparison, the amount of data transfer grouped during off-peak hours is calculated based on usage from 05.01 PM to 06.59 AM West Indonesian time. Table I-IV state the parameter and variables for each case.

TABLE I. Parameters of The C-RAN Selfish User Model for Case 1 and Case 2

Case 1: H_0 as constant and L^H as variable and Case 2: H_0 dan L^H as constant	
H_0	Bandwidth determined by ISP
φ_{eff}	Bandwidth pricing (Rp)
L_C^R	Busy hour bandwidth usage limit
L_{bh}	Bandwidth usage limit for off-peak hours
τ_R	QoS upper limit
τ_{ER}	QoS lower limit
δ_0	Maximum limit of user bandwidth usage
L_{max}^R	Maximum switching bandwidth
b_k^R	Maximum and minimum bandwidth usage
$c_{k,m}^R$	Daily bandwidth usage (kbps)
P	Costs incurred by users to join the service
P_X	Fees set by rush hour service provider
P_Y	Fees set by service provider off-peak hours
$U_{i(X_i,Y_i)}$	User utility function i for peak and off-peak usage rates

TABLE II. Parameters of the C-RAn Selfish User Model for Case 3 and Case 4

Case 3: H_0 as variable and L^H as constant and Case 4: H_0 and L^H as variables	
φ_{eff}	Bandwidth pricing (Rp)
L_C^R	Busy hour bandwidth usage limit
L_{bh}	Bandwidth usage limit for off-peak hours
τ_R	QoS upper limit
τ_{ER}	QoS lower limit
δ_0	Maximum limit of user bandwidth usage
L_{max}^R	Maximum switching bandwidth
b_k^R	The highest and lowest amount of consumption of bandwidth
$c_{k,m}^R$	The consumption of bandwidth per day (kbps)
L^H	Initial usage of bandwidth
P	Costs incurred by users to join the service
P_X	Fees set by ISP on peak hours
P_Y	Fees set by ISP on off-peak hours
$U_{i(X_i,Y_i)}$	Function of preference for User i in peak and off-peak usage rates

TABLE III. Variables of the C-RAn Selfish User Model for Case 1 and Case 2

Case 1: H_0 as constant and L^H as variable and Case 2: H_0 dan L^H as constant	
$e_{k,m}$	Indication of RB allocation indicator of value 0 or 1
$f_{k,m}$	The amount of transferred bandwidth from RB to RUE
b_m^{R2L}	Path loss of RRH on RB
c_m^{R2L}	Channel gain of RRH on RB
L^H	Starting bandwidth usage
b_k^L	Path loss indication from RB to RUE
$c_{k,m}^L$	Channel gain indication from RB to RUE
B_0	Bandwidth usage when in idle
Ω	Utility function focussed on received throughput and Usage
C_{if} dan E_{if}	Throughput amount and energy maintained by the user
w_1 dan w_2	Weight value

TABLE IV. Variables of the C-RAn Selfish User Model for Case 3 and Case 4

Case 3: H_0 as variable and L^H as constant and Case 4: H_0 and L^H as variables	
H_0	Bandwidth determined by ISP
$e_{k,m}$	Indication of RB allocation with a value of 0 or 1
$f_{k,m}$	Bandwidth transfered from RB to RUE
b_m^{R2L}	Corresponding path loss of RRH on RB
c_m^{R2L}	Corresponding channel gain of RRH on RB
L^H	Initial bandwidth usage
b_k^L	Path loss from RB to RUE
$c_{k,m}^L$	Channel gain indication from RB to RUE
B_0	Bandwidth usage when in idle
Ω	Utility function focussed on received throughput and Usage
C_{if} and E_{if}	Throughput amount and energy maintained by the user
w_1 and w_2	Weight value

TABLE V . Parameter Values in SISFO Traffic Data

Parameter	Value (In kbps)	Parameter	Value (In kbps)
$b_1^R = \bar{X}_1$	25021.48111	$b_4^R = \bar{Y}_1$	15782.29295
$b_2^R = \bar{X}_2$	22386.42125	$b_5^R = \bar{Y}_2$	9796.603027
$b_3^R = X_i$	2066.816817	$b_6^R = Y_i$	1467.077874
c_{11}^R	7755.4205	c_{13}^R	28391.8008
c_{12}^R	13779.4816	c_{23}^R	19602.0966
c_{21}^R	10437.4223	c_{33}^R	20179.8491
c_{22}^R	10018.3552	c_{44}^R	8057.5890
c_{31}^R	24602.5643	c_{45}^R	22639.8173
c_{32}^R	16172.0557	c_{46}^R	19679.0511
c_{41}^R	16672.0204	c_{54}^R	34020.7898
c_{42}^R	17107.9421	c_{55}^R	38168.7142
c_{51}^R	11950.1811	c_{56}^R	26752.6567
c_{52}^R	11282.5655	c_{64}^R	19335.7277
c_{61}^R	18636.9533	c_{65}^R	16977.5725
c_{62}^R	25381.0206	c_{66}^R	21212.3376

TABLE VI. PARAMETER VALUES FOR SELFISH USER C-RAN MODEL

Parameter	Value		
	flat-fee	usage-based	two-part tariff
H_0	5000	5000	5000
φ_{eff}	500	500	500
L_C^R	4500	4500	4500
L_{bh}	4000	4000	4000
τ_R	128	128	128
τ_{ER}	64	64	64
δ_0	4500	4500	4500
L_{max}^R	500	500	500
L^H	150	150	150
w_1	1	1	1
w_2	2	2	2
J	25021.48111	25021.48111	25021.48111
Z	15782.2925	15782.2925	15782.2925

Internet financing scheme model based on traffic data

By using the parameter values of Table V and Table VI, then a model will be arranged based on the Objective Function (1) with Constraints (1a) to (1l) as follows :

The Improved C-RAN-*Selfish User* Model based on the Perfect Substitute utility function is as follows.

$$\text{Max}\ \frac{\sum_{k=1}^{K+L}\sum_{m=1}^{M} a_{k,m} L_0 \log_2(1+\sigma_{k,m} t_{k,m})}{\varphi_{eff}\sum_{k=1}^{K+L}\sum_{m=1}^{M} a_{k,m} t_{k,m} + T_c^R T_{bh}}$$

$$+\frac{\left[\sum_i c_{if}\right]^{w1}+\left[\sum_i c_{if}\right]^{w2}}{\sum_i c_{if}+\sum_i c_{if}} + aX + bY - R_X X_i - R_Y Y_i - RZ_i$$

Subject to

$$\sum_{k=1}^{K+L}\sum_{m=1}^{M} a_{k,m} = 1 \qquad ; a_{k,m} \in \{0,1\} \quad (1a)$$

$$\sum_{k=1}^{K} C_{k,m} \geq \tau_R \qquad ; n \in \Omega_1 \quad (1b)$$

$$\sum_{k=K+1}^{K+L} C_{k,m} \geq \tau_{ER} \qquad ; n \in \Omega_2 \quad (1c)$$

$$\sum_{k=K}^{K+L} a_{k,m} t_{k,m} d_m^{R2L} h_m^{R2L} \leq \delta_0 \qquad ; n \in \Omega_{II} \quad (1d)$$

$$\sum_{k=1}^{K+L}\sum_{m=1}^{M} a_{k,m} t_{k,m} \leq T_{max}^R \qquad ; t_{k,m} \geq 0 \quad (1e)$$

$$\sum_i E_{if} \leq P_f \quad , i = (1,2,3,\dots,n) \quad (1f)$$

$$X_i \leq \bar{X}_i Z_i \quad (1g)$$

$$Y_i \leq \bar{Y}_i Z_i \quad (1h)$$

$$U_i(X_i, Y_i) - R_X X_i - R_Y Y_i - RZ_i \geq 0 \quad (1i)$$

$$Z_i = 0 \text{ or } 1 \quad (1j)$$

with

$$C_{k,m} = a_{k,m} L_0 log_2\left(1 + \sigma_{k,m} t_{k,m}\right) \quad (1k)$$

$$\sigma_{k.m} = \begin{cases} \dfrac{d_k^R h_{k,m}^R}{L_0 R_0} & ; n \in \Omega_1 \\ \dfrac{d_k^R h_{k,m}^R}{T^L d_k^L h_{k,m}^L + L_0 R_0} & ; n \in \Omega_2 \end{cases} \quad (1l)$$

Based on the Traffic data shown in Table V and the determination of the parameter values in Table VI, the preparation of this internet financing scheme model was modified into 4 cases based on the initial usage conditions and the predetermined bandwidth consumption.

Max

$$\frac{\sum_{k=1}^{K+L}\sum_{m=1}^{M} a_{k,m} L_0 \log_2(1+\sigma_{k,m} t_{k,m})}{\varphi_{eff}\sum_{k=1}^{K+L}\sum_{m=1}^{M} a_{k,m} t_{k,m} + T_c^R T_{bh}} + \frac{\left[\sum_i C_{if}\right]^{w_1}\left[\sum_i E_{if}\right]^{w_2}}{\sum_i C_{if} + \sum_i E_{if}}$$

$$+aX + bY - R_X X_i - R_Y Y_i - RZ_i =$$

Max

$$\frac{\sum_{k=1}^{3+3}\sum_{m=1}^{3} a_{k,m} L_0 \log_2(1+\sigma_{k,m} t_{k,m})}{\varphi_{eff}\sum_{k=1}^{3+3}\sum_{m=1}^{3} a_{k,m} t_{k,m} + T_c^R T_{bh}} + \frac{\left[\sum_i C_{if}\right]^{w_1}\left[\sum_i E_{if}\right]^{w_2}}{\sum_i C_{if} + \sum_i E_{if}}\ For$$

$$+aX + bY - R_X X_i - R_Y Y_i - RZ_i$$

TABLE VII. COMPARISON AMONG ORIGINAL C-RAN, C-RAN SELFISH USER, AND IMPROVED C-RAN-SELFISH USER PERFECT SUBSTITUTE UTILITY FUNCTION FOR CASE 1

	Original C-RAN	**C-RAN -*Selfish User***	***Improved* C-RAN-*Selfish User- Perfect Substitute Utility Function***		
			Flat-Fee	***Usage-Based***	***Two-Part Tariff***
State	Optimally local	Optimally local	Optimally local	Optimally local	Optimally local
Objective Value	0.0211042	5.2497×10^{17}	5.2497×10^{17}	5.2497×10^{17}	5.2497×10^{17}
Infeasibility	1.42109×10^{14}	1.42109×10^{14}	1.42109×10^{14}	0	1.2109×10^{14}
Iterations	65	45	45	43	59
Update Interval to be updated	2	2	2	2	2
GMU	66	70	73	76	76
ER (Sec)	0	0	0	0	0

TABLE VIII. COMPARISON AMONG ORIGINAL C-RAN, C-RAN SELFISH USER, AND IMPROVED C-RAN-SELFISH USER PERFECT SUBSTITUTE UTILITY FUNCTION FOR CASE 2

			Improved* C-RAN-*Selfish User- Perfect Substitute Utility Function		
	Original C-RAN	**C-RAN -*Selfish User***	***Flat-Fee***	***Usage-Based***	***Two-Part Tariff***
State	Optimally local	Optimally local	Optimally local	Optimally local	Optimally local
Objective	0.0211042	5.2497×10^{17}	5.2497×10^{17}	5.2497×10^{17}	5.2497×10^{17}
Infeasibility	1.42109×10^{14}	1.42109×10^{14}	1.42109×10^{14}	1.42109×10^{14}	1.42109×10^{14}
Iterations	65	45	45	59	59
Update Interval to be updated	2	2	2	2	2
GMU	66	70	73	76	76
ER (Sec)	0	0	0	0	0

TABLE IX. COMPARISON AMONG ORIGINAL C-RAN, C-RAN SELFISH USER, AND IMPROVED C-RAN-SELFISH USER PERFECT SUBSTITUTE UTILITY FUNCTION FOR CASE 3

			Improved* C-RAN-*Selfish User- Perfect Substitute Utility Function		
	Original C-RAN	**C-RAN -*Selfish User***	***Flat-Fee***	***Usage-Based***	***Two-Part Tariff***
Model Class	MINLP	MINLP	MINLP	MINLP	MINLP
State	Optimally local	Optimally local	Optimally local	Optimally local	Optimally local
Objective	0.000127473	5.2497×10^{17}	1.32784×10^{12}	5.2497×10^{17}	1.32784×10^{12}
Infeasibility	1.42109×10^{14}	4.23429×10^{17}	5.68434×10^{14}	2.84217×10^{12}	5.68434×10^{14}
Iterations	122	163	185	168	185
Update Interval to be updated	2	2	2	2	2
GMU	62	66	76	76	76
ER (Sec)	0	1	0	1	1

TABLE X. COMPARISON AMONG ORIGINAL C-RAN, C-RAN SELFISH USER, AND IMPROVED C-RAN-SELFISH USER PERFECT SUBSTITUTE UTILITY FUNCTION FOR CASE 4

			Improved* C-RAN-*Selfish User- Perfect Substitute Utility Function		
	Original C-RAN	**C-RAN -*Selfish User***	***Flat-Fee***	***Usage-Based***	***Two-Part Tariff***
Model Class	MINLP	MINLP	MINLP	MINLP	MINLP
State	Optimally local	Optimally local	Optimally local	Optimally local	Optimally local
Objective	0.000127473	5.2497×10^{17}	5.2497×10^{17}	5.2497×10^{17}	5.2497×10^{17}
Infeasibility	0	4.23429×10^{17}	1.67688×10^{12}	1.67688×10^{12}	1.67688×10^{12}
Iterations	122	163	145	145	145
Update Interval to be updated	2	2	2	2	2
GMU	62	66	76	76	76
ER (Sec)	0	0	0	0	0

Based on the table of recapitulation results of the local Traffic Sisfo server data usage model, it can be concluded that the C-RAN-Selfish User-Utilities Perfect Substitute model obtained the optimal solution in case 1 with a usage-based financing scheme of 5.2497×10^{17} with the objective value is the profit value obtained in the optimal solution.

Sensitivity analysis was conducted to assess the change of coefficient value of objective function. For example, for case 1 according to the tree pricing schemes, then the sensitivity analysis was displayed on Table XI-XIII.

TABLE XI. SENSITIVITY ANALYSIS USING LINGO 13.0 FOR CASE 1 OF FLAT FEE PRICING SCHEME

Variable	*Allowable Increase*	*Allowable Decrease*
a_{11}	0	∞
a_{12}	0	∞
a_{21}	0	∞
a_{22}	0	∞
a_{31}	0	∞
a_{32}	∞	0
a_{41}	0	∞
a_{42}	0	∞
a_{43}	0	∞
a_{51}	0	∞
a_{52}	0	∞
a_{53}	0	∞
a_{61}	∞	0
a_{62}	0	∞
a_{63}	0	∞

TABLE XII. SENSITIVITY ANALYSIS USING LINGO 13.0 FOR CASE 1 OF USAGE BASED PRICING SCHEME

Variable	*Allowable Increase*	*Allowable Decrease*
a_{21}	0	∞
a_{22}	0	∞
a_{31}	0	∞
a_{32}	0	∞
a_{41}	∞	0
a_{42}	∞	0
a_{43}	0	∞
a_{51}	0	∞
a_{52}	0	∞
a_{53}	0	∞
a_{61}	0	∞
a_{62}	0	∞
a_{63}	0	∞
t_{63}	0	0

TABLE XIII. SENSITIVITY ANALYSIS USING LINGO 13.0 FOR CASE 1 OF TWO PART TARIFF PRICING SCHEME

Variable	*Allowable Increase*	*Allowable Decrease*
a_{11}	0	∞
a_{12}	0	∞
a_{21}	0	∞
a_{22}	0	∞
t_{22}	0	0
a_{31}	0	∞
a_{32}	0	∞
a_{41}	∞	0
a_{42}	∞	0
a_{43}	0	∞
a_{51}	0	∞
a_{52}	0	∞
a_{53}	0	∞
a_{61}	0	∞
a_{62}	0	∞
a_{63}	0	∞

As Table XI shows, for instance, the value of a_{11}, a_{12}, a_{21}, and a_{31} in case 1 of flat fee scheme, can be decreased into infinity without affecting the value of objective function value whereas, a_{32} can be increased into infinity without changing the value of the objective function.

IV. CONCLUSION

Based on the results and discussion obtained, it can be concluded :

1. The C-RAN-Selfish-User model is formulated and applied to Traffic Sisfo data based on the Perfect Substitute utility function by adding three internet financing schemes – flat-fee, usage-based, and two-part tariff, obtained as many as 12 models. The model is divided into 4 cases, each case consisting of 3 financing schemes according to Model 1.
2. The most optimum solution is obtained from the Improved C-RAN-Selfish User model–Perfect Substitute utility function in case 1 with a usage-based financing scheme of 5.2497×10^{17}.
3. Based on the results of the comparison of optimal solutions, the optimal solution obtained from the C-RAN–Selfish User–perfect substitute utility function is better than the original C-RAN model and the improved C-RAN–Selfish User model. ISP increases profits by utilizing financing schemes.
4. The results of the sensitivity analysis using the LINGO 13.0 software for the variable $e_{k,m}$, and the variable $f_{k,m}$ which have an ∞, meaning that the increase and decrease can be changed while the value 0 meaning that the increase and decrease values will remain unchanged.

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