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Improved Dynamic Spectrum and Traffic Management Model Based on Demand Response and Heterogeneous Incentives with Perfect Substitute Utility Function

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Abstract
The purpose of this research is to design and optimize a demand response based-selfish user Cloud Radio Access Network (C-RAN) model to demonstrate with a narrow-minded client utilizing three financing plans specifically level charge, usage-based, and two-part tariff. The Traffic data is classified into incoming data and outgoing data, obtained from a local server in Palembang. The optimal solution is obtained by determining the decision variables and parameters used in each case for all models, compiling improved C-RAN models as many as 2 models, namely model I, and model II, and then determining the optimal solution and sensitivity analysis using LINGO 13.0 software. The most optimal solution is obtained from model II with a flat-fee scheme in case 1 of IDR 3299.7/kbps with 45 iterations. The results of the sensitivity analysis is on the variables $a_{k,m}$ that allows the increase and decrease in the objective function coefficient. At the same time, the value 0 will be constant.

Keywords
C-RAN, Selfish User, Demand Response, Heterogeneous Incentives, Sensitivity Analysis

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1. INTRODUCTION

Nowadays, communication technology is developing very fast, especially on the Internet (Fagbohun, 2014; Samunderu and Farrugia, 2022). Communication technology faces critical issues to provide the best technology to persuade consumers appliying the technology. The Internet is a communication network with an electronic support function with another person quickly and accurately. As a service provider, the internet is provided by Internet Service Providers (ISPs) (Hussein et al., 2023). ISPs as a provider company must be able to provide the best quality of service (QoS) to users so that it is beneficial for ISPs and internet users (Dai et al., 2018). QoS is defined as user satisfaction, so internet access is not only influenced by network performance but also influenced by the service performance of the ISPs (Lasemi et al., 2023; Xu et al., 2021). According to Jiang and Mahmoodi (2016), selfish users in management must prioritize using Quality of Experience (QoE).

A bundling strategy is a strategy that is carried out to increase profits by utilizing methods in the form of combining existing services (Hemmati et al., 2023; Mondal and Giri, 2024; Puspita et al., 2020). This model also uses a utility function and reverse charging models (Indrawati et al., 2021; Puspita et al., 2020). The utility function used in this study is the perfect substitute utility function which aims to measure the level of satisfaction of users by optimizing benefits for users (Gaudin et al., 2001). Dynamic Spectrum Management (DSM) refers to a set of techniques to reduce crosstalk effects that affect the best performance (Gizelis and Vergados, 2011). In maximizing user satisfaction, 3 pricing schemes should be determined, namely flat-fee, usage-based, and two-part tariff (Zhang et al., 2023). Several ways regarding to DSM can be done for electric power generation, one of which is Demand Response (DR) (Alquthami et al., 2021; Bolurian et al., 2023). Heterogeneous Incentives (IH) Bonjean (2019) are also needed when using the internet. IH is a service that is set in such a way that users do not have different intentions when paying for the service. According to Rodoshi et al. (2020), the Cloud radio access network (C-RAN) model is expected to be one of the key technologies in the development of 4G and future wireless networks with the proposed pricing scheme (Wang et al., 2023; Zheng and Geroliminis, 2020).

The challenge in developing traffic management quickly is very critical, the tendency to use conventional traffic management is not suitable in this generation for example using spectrum sharing (Nidhi et al., 2021). It needs management that can fit with a current situation involving the DR and IH-based selfish user C-RAN model (Rodoshi et al., 2020).

The previous model discussed only involved C-RAN selfish users and fair networks, without considering DR and IH-for maintaining dynamic spectrum and traffic management efficiently. It needs to be improved by developing DR and IH-based Selfish User C-RAN model Indrawati et al. (2020) with perfect substitute utility function-bundling based, utilizing three financing schemes of flat-fee, usage-based, and two-part tariff to prioritize the level of usage' satisfaction (Ashe and Wilson, 2020; Mondal and Giri, 2024). In addition, sensitivity analysis is performed to minimize the effect of variable changes on the objective function. The comparison of the optimal solution using LINGO 13.0 software is between Model I (C-RAN selfish user based on DR and IH with perfect substitute utility function) and Model II (C-RAN selfish user based on DR and IH with perfect substitute utility function combined with bundling) with three financing schemes. It is expected that the developed model shows how effectively the use of utility functions to maximize the profit of ISPs. The developed model can be verified that the evaluated functionality can generate maximum benefits for ISPs and can be validated by performing sensitivity analysis (Derbel et al., 2021; Ely et al., 2021) to mitigate changes in the objective function.

2. EXPERIMENTAL SECTION

2.1 Methods

The methods are explained as follows.

1. Describe the local traffic Sisfo data for 30 days starting from April 16, 2024, to May 15, 2024. The data is secondary data and is obtained from a local server in Palembang, which is divided into two groups, namely busy hours and off-peak hours. Peak hours start from 07.00 AM to 05.00 PM Indonesian Time. Off-peak hours start from 07.00 PM to 05.00 AM Indonesian Time where each group consists of inbound and outbound data.
2. Determine the value of decision variables and parameters in the C-RAN selfish user model based on DR and IH perfect substitute utility function and bundling scheme. Bandwidth consumption on the network is divided into 4 cases:
   a. L_0 is to be fixed and T^L as variables.
   b. L_0 and T^L is to be fixed.
   c. L_0 as variables and T^L to be fixed.
   d. L_0 and T^L as variables.
3. Design an improved C-RAN selfish user model based on DR and IH based on perfect substitute utility function and bundling scheme, which consists of objective functions and constraints.
4. Determine the optimal solution and analyze the results obtained from model I and model II with LINGO 13.0.
5. Compare the optimal solutions of model I and model II with flat-fee, usage-based, and two-part tariff financing schemes.
6. Apply the sensitivity analysis of the objective function coefficient with LINGO 13.0 software.

3. RESULTS AND DISCUSSION

This part discusses the improved dynamic spectrum and traffic management financing scheme model based on DR and IH using the perfect substitute utility function. In solving optimization problems, data is needed to complete calculations to obtain optimal solution results. The data used is secondary data and obtained from a local server in Palembang. The data collection process is carried out over one month, starting on April 16, 2024 - May 15, 2024.

3.1 Traffic Data Description

QoS data for traffic is internet usage data. The data is divided into 2 sessions, namely peak hour data and off-peak hour data consisting of inbound and outbound data expressed in units of bits per second. Table 1 explains the data taken and the classification of data into two parts is presented in Table 2.

Table 1. Traffic Data Sisfo Formed into 24 Data (≥ 3,400 kbps)

Bit	Per Day Byte	Kilo Byte
33,993,866.74344	4,249,233.343	4,149.641936
53,502,941.00378	6,687,867.625	6,531.120728
73,154,659.82036	9,144,332.478	8,930.012185
30,691,305.35705	3,836,413.17	3,746.497236
47,862,350.58014	5,982,793.823	5,842.572092
35,277,818.74012	4,409,727.343	4,306.374358
51,530,166.06748	6,441,270.758	6,290.303475
41,056,910.02631	5,132,113.753	5,011.829837
53,589,817.53077	6,698,727.191	6,541.725773
57,707,667.34549	7,213,458.418	7,044.392987
36,703,086.91590	4,587,885.864	4,480.35729
36,764,644.67387	4,595,580.584	4,487.871664
46,588,386.22437	5,823,548.278	5,687.058865
49,923,810.52614	6,240,476.316	6,094.215152
28,214,578.03671	3,526,822.255	3,444.162358
31,336,212.69274	3,917,026.587	3,825.221276
40,834,205.91447	5,104,275.739	4,984.644277
28,380,588.75128	3,547,573.594	3,464.427338
60,141,620.82301	7,517,702.603	7,341.506448
35,569,587.16896	4,446,198.396	4,341.990621
41,962,178.39202	5,245,272.299	5,122.336229
34,232,485.15066	4,279,060.644	4,178.77016
37,623,182.98331	4,702,897.873	4,592.673704
42,947,567.33251	5,368,445.917	5,242.622965

Description:
$\bar{X}_1$: Maximum average usage during peak hours in units of kilobytes per second.
$\bar{X}_2$: Average of the second highest usage during peak hours in kilobytes per second.

$\bar{X}_i$: The minimum usage during peak hours in kilobytes per second.
$\bar{Y}_1$: Average maximum usage during off-peak hours in kilobytes per second.
$\bar{Y}_2$: Average second-highest usage during off-peak hours in kilobytes per second.
$\bar{Y}_i$: Minimum usage during off-peak hours in units of kilobytes per second.

Table 2. Sisfo Traffic Data for Peak and Off-Peak Hours

Consumption Rate	Total Traffic Consumption per Day		
	Bit	Byte	Kbyte
$\overline{X}_1$	28467128.89796	3558391.112	3474.991321
$\overline{X}_2$	26623360.00906	3327920.001	3249.921876
X_i	4579953.72412	572494.2155	559.0763823
$\overline{Y}_1$	44687530.92	5585941.365	5455.020865
$\overline{Y}_2$	44469209.87	5558651.234	5428.370345
Y_i	2034676.133	254334.5166	248.3735513

Parameter and variable definitions for selfish users of all cases are as follows.
ϕ_{eff} : The bandwidth price determination (IDR).
T_C^R : The peak hour bandwidth usage limit.
T_{bh} : The off-peak hour bandwidth usage limit.
τ_R : The maximum value of QoS.
τ_{ER} : The minimum value of QoS.
δ_0 : The highest value usage of the user bandwidth limit.
T_{max}^R : The upper limit of bandwidth displacement.
d_k^R : The maximum and minimum use of bandwidth.
$h_{(k,m)}^R$: The total use of bandwidth(daily in kilobytes per second).
R : The amount of fares users had to spend to follow the plan.
R_X : The fares by service providers in 7.00 AM-5.00 PM service.
R_Y : The fares by service providers in 5.00 AM-7.00 PM service.
$U_{i(X_i,Y_i)}$: The user i satisfaction in all periods.

Case 1 : L_0 is to be fixed and
T^L is to be varied
L_0 : The ISP-determined bandwidth
Case 2 : L_0 and T^L are to be fixed
L_0 : The ISP-determined bandwidth.
T^L : The initial bandwidth usage.
Case 3 : T^L are to be fixed
T^L : Initial bandwidth usage.
Case 4 : L_0 and T^L as variables, all notations are used.

Next, selfish user C-RAN model variable definitons are as follows.
$a_{k,m}$: Indicator of allocation of RB with 0 or 1 values.
$a_{k,m}$: RB to RUE bandwidth allocations.
d_m^{R2L} : Signal degradation of RRH on RB.
h_m^{R2L} : Signal amplification of RRH at RB.
d_k^L : Signal degradation from RB to RUE.
$h_{k,m}^L$: Signal amplification from RB to RUE.
R_0 : Data transfer when not hosting.
w_1 and w_2 : The weight value.

Case 1 : L_0 is to be fixed and T^L is to be varied
T^L : Initial bandwidth usage.
Case 2 : L_0 and T^L is to be fixed, all variables are defined before.
Case 3 : L_0 is to be varied and
T^L is to be fixed
L_0 : The bandwidth provision set by the ISPs.
Case 4 : L_0 and T^L are to be varied
L_0 : The bandwidth provision set by the ISPs.
T^L : Initial bandwidth usage.

Then, the parameters for each bundling model are stated as follows.
B_j : A payment was made for a bundle for each service j.
I : Target markets.
M : The additional cost incurred for user i when adding bundle to the menu.
V_{ik} : The additional cost incurred for user i for each preferred bundle k to the menu.
R_{ij} : The total amount a user i pays is calculated based on their engagement with different j services.

Decision variables for the bundling model are stated as follows.
P_j : The rate set for each bundle of service j.
S_i : The profit on use for the i-th consumer.
X_{ij} : 1 if the i-th consumer has bundled in service j or 0 otherwise.
Y_j : 1 if ISPs serve bundling in service j.
Table 3 states the parameter value of the C-RAN model, Table 4 shows the parameter values used in the financing scheme, Table 5 explains the parameter values used in the original bundling model, and Table 6 states the parameter values on the data,

3.2 Model I (Improved C-RAN Selfish User based on DR & IH Based on Perfect Substitute Utility Function)

After building parameters and variables, the next step is to develop the C-RAN model that needs to be improved. This model is obtained by combining the C-RAN model with DR & IH user network, then adding the replacement function that is perfectly appointed in Equation 1, and subject to a set of constraints, stated in Equation 2 to Equation 16 as follows:

Table 3. Constant Values of the C-RAN Model

Parameters	Value of Each Scheme
L_0	5000
φ_{eff}	4500
T_R	4000
T_B	200
τ_E	64
$\tau_{R_{\max}}$	450
Σ_1	150
T^R_{max}	500
T_l	150

Table 4. Constant Values Used in The Financing Scheme

Parameters	Value of Each Scheme
W_1, W_2	1 and 2
X	3,474.991321
Y	5,455.020865

Table 5. Constant Values Used in The Original Bundling Model

Parameters	Value
V_{11}, V_{12}, V_{13}	800, 200, and 350
V_{21}, V_{22}, V_{23}	500, 650, and 200
V_{31}, V_{32}, V_{33}	400, 600, and 350
M	150
B_1, B_2, B_3	650, 450, and 200

$$\begin{aligned}\max \quad & \frac{\sum_{k=1}^{K+L}\sum_{m=1}^{M} a_{k,m} L_0 \log_2(1+\sigma_{k,m}t_{k,m})}{\varphi_{eff}\sum_{k=1}^{K+L}\sum_{m=1}^{M} a_{k,m}t_{k,m} + \tau^c R^T_{bh}} \\ & + \frac{\left[\sum_i C_{if}\right]^{w_1}\left[\sum_i E_{if}\right]^{w_2}}{\sum_i C_{if} + \sum_i E_{if}} + aX + bY \\ & + \hat{A} - \pi_a T_a + h_p Q_a - \\ & \left(e(Q_a - q_a)^2 + R_X X_i + R_Y Y_i + RZ_i\right)\end{aligned} \tag{1}$$

subject to

$$\sum_{k=1}^{K+L}\sum_{m=1}^{M} a_{k,m} = 1 \quad ; \quad a_{k,m} \in \{0,1\} \tag{2}$$

$$\sum_{k=1}^{K} C_{k,m} \geq \tau_R \quad ; \quad m \in \Omega_1 \tag{3}$$

$$\sum_{k=K+1}^{K+L} C_{k,m} \geq \tau_{ER} \quad ; \quad m \in \Omega_2 \tag{4}$$

$$\sum_{k=K}^{K+L} a_{k,m}t_{k,m}d_m^{R2L}h_m^{R2L} \leq \delta_0 \quad ; \quad m \in \Omega_{II} \tag{5}$$

$$\sum_{k=1}^{K+L}\sum_{m=1}^{M} a_{k,m}t_{k,m} \leq T^R_{\max} \quad ; \quad t_{k,m} \geq 0 \tag{6}$$

$$\sum_i E_{if} \leq P_f \quad = \quad i = 1, 2, 3, \ldots, n \tag{7}$$

$$\hat{A} = AP + \pi_b(T_a - T_b) + \frac{\pi_b}{2ET_b}(T_a - T_b)^2 \tag{8}$$

$$D_a \geq Q - q_a \tag{9}$$

$$Q_a - q_a = \frac{h_p}{2e} \tag{10}$$

$$\frac{h_p}{Qa - qa} < 2e \tag{10}$$

$$Q_a \geq q_a \tag{11}$$

$$X_i \leq \tilde{X}_i Z_i \tag{13}$$

$$Y_i \leq \tilde{Y}_i Z_i \tag{14}$$

$$(P_i - \gamma_i)_i^{\beta} + (R_i - \gamma_i)_i^{\beta} - R_X X_i - R_Y X_i - R_Z Z_i \geq 0 \tag{15}$$

$$Z_i = 0 \text{ or } 1 \tag{16}$$

with :

$$C_k, m = a_{k,m} Lo \log_2\left(1 + \sigma_{k,m}t_{km}\right)$$

$$\sigma_{k,m} = \begin{cases} \frac{d^R_{k,m}h^R_{k,m}}{L_0R_0} & ; n \in \Omega_1 \\ \frac{h^R_k d^R_{k,m}}{T^L h^L_k d^L_{k,m} + L_0R_0} & ; n \in \Omega_2 \end{cases}$$

Table 6. Constant Values on Sisfo Traffic Data

Parameters	Value (in kbps)
$d_1^R = \bar{X}_1$	3,474.991321
$d_2^R = \bar{X}_2$	3,249.921876
$d_3^R = X_\mathrm{i}$	559.0763823
$d_4^R = \bar{Y}_1$	5,455.020865
$d_5^R = \bar{Y}_2$	5,428.370345
$d_6^R = Y_\mathrm{i}$	248.3735513
$h_1^R 1, h_{12}^R$	4,149.641936 and 6,531.120728
$h_2^R 1, h_{22}^R$	8,930.012185 and 3,746.497236
$h_3^R 1, h_{32}^R$	5,842.572092 and 4,306.374358
$h_4^R 1, h_{42}^R$	6,290.303475 and 5,011.829837
$h_5^R 1, h_{52}^R$	6,541.725773 and 7,044.392987
h_{61}^R	4,480.35729
h_{62}^R	4,487.871664
h_{13}^R	5,687.058865
h_{23}^R	6,094.215152
h_{33}^R	3,444.162358
h_{44}^R	3,825.221276
h_{45}^R	4,984.644277
h_{46}^R	3,464.427338
h_{54}^R	7,341.506448
h_{55}^R	4,341.990621
h_{56}^R	5,122.336229
h_{64}^R	4,178.77016
h_{65}^R	4,592.673704
h_{66}^R	5,242.622965

Table 7. Parameter Values for The Selfish User Model

Parameters	Value
T	2 hours
π	3.14
β	0.5
e	2.71
d	10,240 kb
η	6 hours
n	2.71

3.3 Model II (Improved C-RAN Selfish User based on DR & IH Based on Utility Function Perfect Substitute and Bundling Scheme)

After formulating the parameters and variables, the next step is to develop an improved C-RAN model. This model is obtained by combining the C-RAN model with the DR & IH-based selfish user network model and then adding the perfect substitute and bundling utility functions. After building parameters and variables, the next step is to develop the C-RAN model that needs to be improved.

This model is available by combining the C-RAN model with a selfish network based on DR & IH, then adding replacement functions and perfect groups indicated in Equation 17, and subject to a set of constraints stated in Equation 18 to Equation 39, as follows:

$$\begin{aligned}\max \quad & \frac{\sum_{k=1}^{K+L}\sum_{m=1}^{M} a_{k,m} L_o \log_2(1+\sigma_{k,m}t_{k,m})}{\varphi_{\mathrm{eff}}\sum_{k=1}^{K+L}\sum_{m=1}^{M} a_{k,m}t_{k,m} + \tau^c R_{bh}^T} \\ & + \frac{\left[\sum_i C_{if}\right]^{w_1}\left[\sum_i E_{if}\right]^{w_2}}{\sum_i C_{if} + \sum_i E_{if}} + aX + bY + \hat{A} \\ & - \pi_a T_a + h_p Q_a - e(Q_a - q_a)^2 - R_X X_i \\ & - R_Y Y_i - R_Z Z_i + \sum_{i=0}^{I}\sum_{j=0}^{J}(P_j - B_j)X_{ij} \\ & - \sum_{j=0}^{J} MY_j \end{aligned} \tag{17}$$

$$\sum_{k=1}^{K+L}\sum_{m=1}^{M} a_{k,m} = 1; \quad a_{k,m} \in \{0, 1\} \tag{18}$$

$$\sum_{k=1}^{K} C_{k,m} \geq \tau_R; \quad m \in \Omega_1 \tag{19}$$

$$\sum_{k=K+1}^{K+L} C_{k,m} \geq \tau_{ER}; \quad m \in \Omega_2 \tag{20}$$

$$\sum_{k=K+1}^{K+L} a_{k,m} t_{k,m} d_m^{R2L} h_m^{R2L} \leq \delta_0; \quad m \in \Omega_{II} \tag{21}$$

$$\sum_{k=1}^{K+L} \sum_{m=1}^{M} a_{k,m} t_{k,m} \leq T_{\max}^R; \quad t_{k,m} \geq 0 \tag{22}$$

$$\sum_i E_{if} \leq P_f; \quad i = 1, 2, 3, \ldots, n \tag{23}$$

$$\hat{A} = AP + \pi_b(T_a - T_b) + \frac{\pi_b}{2E_{T_b}}(T_a - T_b)^2 \tag{24}$$

$$D_a \geq Q - q_a \tag{25}$$

$$Q_a - q_a = \frac{h_p}{2e} \tag{26}$$

$$\frac{h_p}{Qa - qa} < 2e \tag{27}$$

$$Q_a \geq q_a \tag{28}$$

$$X_i \leq \tilde{X}_i Z_i \tag{29}$$

$$Y_i \leq \tilde{Y}_i Z_i \tag{30}$$

$$(P_i - \gamma_i)_i^\beta + (R_i - \gamma_i)_i^\beta - R_X X_i - R_Y X_i - R_Z Z_i \geq 0 \tag{31}$$

$$Z_i = 0 \text{ or } 1 \tag{32}$$

$$S_i \geq (R_{ij} - P_j)Y_j, i = 1, 2, \cdots, 3; j = 1, 2, \cdots, 3 \tag{33}$$

$$\begin{aligned} S_1 &= (R_{11} - P_i)X_{ij} + (R_{12} - P_2)X_{12} + \\ &\qquad (R_{13} - P_3)X_{13} \\ S_2 &= (R_{21} - P_1)X_{21} + (R_{22} - P_2)X_{22} + \\ &\qquad (R_{13} - P_3)X_{23} \\ S_3 &= (R_{31} - P_1)X_{31} + (R_{32} - P_2)X_{32} + \\ &\qquad (R_{33} - P_3)X_{33} \end{aligned} \tag{34}$$

$$(R_{ij} - P_j)X_{ij} \geq 0, i = 1, 2, \cdots, 3; j = 1, 2, \cdots, 3 \tag{35}$$

$$\begin{aligned} X_{11} + X_{12} + X_{13} &\leq 1 \\ X_{21} + X_{22} + X_{23} &\leq 1 \\ X_{31} + X_{32} + X_{33} &\leq 1 \end{aligned} \tag{36}$$

$$X_{ij} \leq Y_j, i = 1, 2, \cdots, 3; j = 1, 2, \cdots, 3 \tag{37}$$

$$\begin{aligned} S_1 &\geq 0 \\ S_2 &\geq 0 \\ S_3 &\geq 0 \end{aligned} \tag{38}$$

$$\begin{aligned} P_1 &\geq 0 \\ P_2 &\geq 0 \\ P_3 &\geq 0 \end{aligned} \tag{39}$$

with :

$$C_k, m = a_{k,m} Lo \log_2\left(1 + \sigma_{k,m} t_{km}\right)$$

$$\sigma_{k,m} = \begin{cases} \frac{d_{k,m}^R h_{k,m}^R}{L_0 R_0} & ; n \in \Omega_1 \\ \frac{h_k^R d_{k,m}^R}{T^L h_k^L d_{k,m}^L + L_0 R_0} & ; n \in \Omega_2 \end{cases}$$

Table 8. Optimal Solution of Model I in Case 3

Solver Status	Flat-fee	Usage-based	Two-Part Tariff
Model Class	NLP	NLP	NLP
State	Local Infeasible	-	Feasible
Objective	-9.8993×10^3	5.2497×10^{17}	5.2497×10^{17}
Infeasibility	1.6×10^{35}	0	2.7755×10^{-17}
Iteration	38	108	115
GMU(K)	72	72	72
ER(Sec)	0	0	0

Table 9. Optimal Solution of Model I in Case 4

Solver Status	Flat-fee	Usage-based	Two-Part Tariff
Model Class	NLP	NLP	NLP
State	Local Infeasible	Unbounded	Feasible
Objective	-1×10^{20}	5.2497×10^{17}	5.2497×10^{17}
Infeasibility	1.6×10^{35}	1.38778×10^{-17}	0
Iteration	42	68	160
GMU(K)	72	72	72
ER(Sec)	0	0	0

Table 10. Optimal Solution of Model II in Case 2

Solver Status	Flat-fee	Usage-based	Two-Part Tariff
Model Class	NLP	NLP	NLP
State	Feasible	Local Inf	Local Opt
Objective	3299.7	3299.7	3299.7
Infeasibility	1.2288×10^{-6}	1.20641×10^{-8}	9.0955×10^{-14}
Iteration	59	47	49
GMU(K)	88	93	93
ER(Sec)	4	2	2

3.4 Model of Internet Financing Scheme Based on Data Usage

After determining the parameter values and variables of the C-RAN selfish user model that has been formed, an internet financing scheme that can maximize profits at the ISP is obtained. The use of RUE against RRH is selected as much as 3 RUEs. The use of RUE against RB has selected as many as 3 RUEs. The use of servers against RB has selected as many as 3 servers. By selecting K=3,L=3,M=2, then

Table 11. Optimal Solution of Model II in Case 3

Solver Status	Flat-fee	Usage-based	Two-Part Tariff
Model Class	NLP	NLP	NLP
State	Local Opt	Local Inf	Local Opt
Objective	3299.7	3299.7	3299.7
Infeasibility	2.37477×10^{-13}	2.65649×10^{-13}	$1.336419 \times 10^{-113}$
Iteration	73	74	77
GMU(K)	93	93	93
ER(Sec)	2	2	2

Table 12. Optimal Solution of Model II in Case 4

Solver Status	Flat-fee	Usage-based	Two-Part Tariff
Model Class	NLP	NLP	NLP
State	Local Opt	Local Inf	Local Opt
Objective	3299.7	3299.7	3299.7
Infeasibility	8.5406×10^{-7}	7.72208×10^{-7}	5.33741×10^{-5}
Iteration	60	60	66
GMU(K)	93	93	88
ER(Sec)	2	2	2

Table 13. Sensitivity Analysis Results on Model II Case 1 Based on Financing Scheme

Variables	Financing Scheme					
	Allowable Increase			Allowable Decrease		
	Flat-Fee	Usage based	Two-Part Tariff	Flat-Fee	Usage-based	Two-Part Tariff
a_{11}	∞	∞	∞	0	0	0
a_{12}	∞	∞	∞	0	0	0
a_{21}	0	0	0	∞	∞	∞
a_{22}	0	0	0	∞	∞	∞
a_{31}	0	0	0	∞	∞	∞
a_{32}	0	0	0	∞	∞	∞
a_{41}	0	0	0	∞	∞	∞
a_{42}	0	0	0	∞	∞	∞
a_{51}	0	0	0	∞	∞	∞
a_{52}	0	0	0	∞	∞	∞
a_{61}	0	0	0	∞	∞	∞
a_{62}	0	0	0	∞	∞	∞

Ω_1=1, 2, 3,$\cdots$,K=1,$\cdots$,3
Ω_2=$K+1$, $K+2$,$\cdots$,$K+L$=4,$\cdots$,6 ;
Ω_{II}=$\Omega_1 \cup \Omega_1$=1,$\cdots$,6
with

Ω_1 : RUE allocation with QoS upper limit.
Ω_1 : Remote RUE Allocation with QoS lower limit.
Ω_1 : RUE allocation with RB.

Table 7 shows the parameter value used in the selfish model with the following parameter values: $\zeta(T) = \frac{\pi^2}{3\beta^2} e^{(-\beta^2 T)}$, $E_i = \zeta(T)\eta d_i^r$ To know the value of $\zeta(T)$, calculate $\zeta(T) = \frac{\pi^2}{3\beta^2} e^{(-\beta^2 T)} = \frac{(3.14)^2}{3(0.5)^2}(2.71)^{(-0.5)^2}(2) = 21.64115$. After obtaining the value $\zeta(T) = 21.64115$, then the next value can be found which is E_i as follows. $E_i = \zeta(T) + \eta d_i^r = 4.4262 \times 10^{11}$. So in the selfish user model, the variable value is $E_i f$.

Table 14. Sensitivity Analysis Results on Model II Case 2 Based on Financing Scheme

Variables	Financing Scheme					
	Allowable Increase			Allowable Decrease		
	Flat-Fee	Usage based	Two-Part Tariff	Flat-Fee	Usage-based	Two-Part Tariff
a_{11}	∞	∞	∞	0	0	0
a_{12}	∞	∞	∞	0	0	0
a_{21}	0	0	0	∞	∞	∞
a_{22}	0	0	0	∞	∞	∞
a_{31}	0	0	0	∞	∞	∞
a_{32}	0	0	0	∞	∞	∞
a_{41}	0	0	0	∞	∞	∞
a_{42}	0	0	0	∞	∞	∞
a_{51}	0	0	0	∞	∞	∞
a_{52}	0	0	0	∞	∞	∞
a_{61}	0	0	0	∞	∞	∞
a_{62}	0	0	0	∞	∞	∞

3.5 Optimal Solution and Variable Values of Improved C-RAN Model

By using LINGO 13.0, the solutions are obtained for each case stated in Table 8 to Table 12. Each case has a different scheme solution.

3.6 Sensitivity Analysis with LINGO 13.0 Software

Sensitivity analysis is used to validate the financing scheme model. The variables have nonlinear values. The results of the sensitivity analysis are presented in Table 13 to Table 16 as follows.

3.7 Evaluation within an Internet Financing Scheme to Determine the Most Effective or Optimal Solutions

A comparison of the optimal solutions for model I and model II based on three internet financing schemes is shown in Table 17 as follows. Table 17 presents the results of the comparison between the optimal solution of 3 internet financing schemes using the additional bundling model (Model II) and the optimal solution of 3 internet financing schemes without bundling (Model I) in each case. The model of the 3 internet financing schemes of model II looks more optimal than model I, this is because the value of the objective value is higher than other model. The model of type II financing scheme with flat-fee financing scheme in case 1 which has an objective value of 3299.7/kbps and 45 iterations is the most optimal solution.

Table 15. Sensitivity Analysis Results on Model II Case 3 Based on Financing Scheme

Variables	Financing Scheme					
	Allowable Increase			Allowable Decrease		
	Flat-Fee	Usage based	Two-Part Tariff	Flat-Fee	Usage-based	Two-Part Tariff
a_{11}	∞	∞	∞	0	0	0
a_{12}	∞	∞	∞	0	0	0
a_{21}	0	0	0	∞	∞	∞
a_{22}	0	0	0	∞	∞	∞
a_{31}	0	0	0	∞	∞	∞
a_{32}	0	0	0	∞	∞	∞
a_{41}	0	0	0	∞	∞	∞
a_{42}	0	0	0	∞	∞	∞
a_{51}	0	0	0	∞	∞	∞
a_{52}	0	0	0	∞	∞	∞
a_{61}	0	0	0	∞	∞	∞
a_{62}	0	0	0	∞	∞	∞

Table 16. Sensitivity Analysis Results on Model II Case 4 Based on Financing Scheme

Variables	Financing Scheme					
	Allowable Increase			Allowable Decrease		
	Flat-Fee	Usage based	Two-Part Tariff	Flat-Fee	Usage-based	Two-Part Tariff
a_{11}	∞	∞	∞	0	0	0
a_{12}	∞	∞	∞	0	0	0
a_{21}	0	0	0	∞	∞	∞
a_{22}	0	0	0	∞	∞	∞
a_{31}	0	0	0	∞	∞	∞
a_{32}	0	0	0	∞	∞	∞
a_{41}	0	0	0	∞	∞	∞
a_{42}	0	0	0	∞	∞	∞
a_{51}	0	0	0	∞	∞	∞
a_{52}	0	0	0	∞	∞	∞
a_{61}	0	0	0	∞	∞	∞
a_{62}	0	0	0	∞	∞	∞

Table 17. Recapitulation of Optimal Solution Comparison

Model	Financing Type	Solver Status						
		Case	Class Model	State	Objective	Infeasibility	Iterations	GMU
Model I	Flat Fee	Case 1	NLP	Local Infeasible	-9.89938 $\times 10^{21}$	1.6×10^{35}	39	72
		Case 2	NLP	Local Infeasible	5.249×10^{17}	128	41	72
		Case 3	NLP	Local Infeasible	-9.89938 $\times 10^{21}$	1.6×10^{35}	38	72
		Case 4	NLP	Local Infeasible	-1×10^{20}	1.6×10^{35}	42	72
	Usage Based	Case 1	NLP	Local Infeasible	-9.89938 $\times 10^{21}$	1.6×10^{35}	28	72
		Case 2	NLP	Local Infeasible	5.249×10^{17}	1.6×10^{35}	36	72
		Case 3	NLP	Feasible	5.249×10^{17}	0	108	72
		Case 4	NLP	Unbounded	5.249×10^{17}	1.38778×10^{17}	68	72
	Two-Part Tariff	Case 1	NLP	Local Infeasible	-1×10^{20}	1.6×10^{35}	76	72
		Case 2	NLP	Local Infeasible	-1×10^{20}	1.6×10^{35}	75	72
		Case 3	NLP	Feasible	5.249×10^{17}	2.7755×10^{-17}	115	72
		Case 4	NLP	Feasible	5.249×10^{17}	0	160	72
Model II (Bundling)	Flat Fee	Case 1	NLP	Local Optimum	3299.7	5.29872×10^{-10}	45	93
		Case 2	NLP	Feasible	3299.7	1.28288×10^{-6}	59	88
		Case 3	NLP	Local Optimum	3299.7	2.37477×10^{-13}	73	93
		Case 4	NLP	Local Optimum	3299.7	8.5406×10^{-7}	60	93
	Usage Based	Case 1	NLP	Local Infeasible	3299.7	1.20641×10^{-8}	46	94
		Case 2	NLP	Local Infeasible	3299.7	1.20641×10^{-8}	47	93
		Case 3	NLP	Local Infeasible	3299.7	2.65649×10^{-13}	74	93
		Case 4	NLP	Local Infeasible	3299.7	7.72208×10^{-7}	60	93
	Two-Part Tariff	Case 1	NLP	Local Infeasible	3299.7	4.05622×10^{-5}	104	89
		Case 2	NLP	Local Optimum	3299.7	9.0955×10^{-14}	49	93
		Case 3	NLP	Local Optimum	3299.7	1.36419×10^{-1}	77	93
		Case 4	NLP	Local Optimum	3299.7	5.33741×10^{-5}	66	88

4. CONCLUSIONS

Based on the results and discussion previously described, the following conclusions are obtained that an Improved C-RAN model can be developed and implemented on sisfo traffic data resulting in 24 models. The most optimal solution is obtained from model II case 1 with a flat-fee financing scheme of Rp 3299.7/kbps with 45 iterations. Therefore, ISPs can use this financing scheme to increase profits. The objective function coefficients of the sensitivity analysis for variables with values of ∞, increase and decrease are not fixed, while those with a value of 0 will be fixed or stable. For Further research, the work can be extended to also include a scheme that allows pure or mixed bundling for having different preferences for consumers.

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