PROJECT 1 Resubmission: Algorithm Design For Making Handover Decisions in Heterogeneous Wireless Network

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0.1 Introduction

Vertical handoff is the ability for users to switch connections between Radio Access Technologies (RATs) in order to satisfy the Always Best-Connected concept. To ensure satisfactory Quality of Service (QoS), mobility management is crucial in heterogeneous networks to ensure seamless and enjoyable service. Focusing on User-centric networks and their preferences, a vertical handover algorithm can be developed following multi-criteria decision-making(MCDM) techniques. Figure 1 shows an overview of the Vertical Handoff decision process.

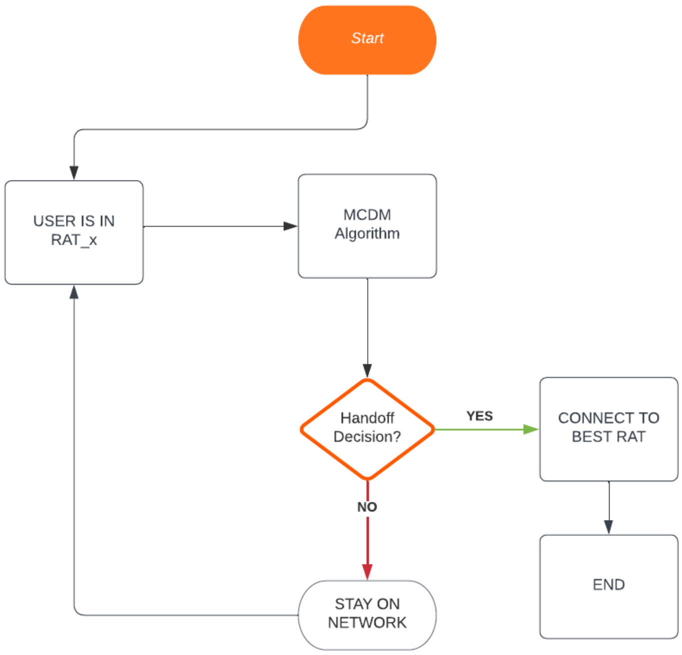

Figure 1: Handoff Decision Overview

MCDM has two subsets namely, MADM and MODM. This investigation is limited to MADM and does not go in depth about MODM. Simple Additive Weighting(SAW) is the chosen method for this investigation. In SAW, the overall score of a RAT is determined by taking the weighted sum of the criteria attributes. The RAT with the highest score is chosen. Figure 2 shows this process. For normalization, a distinction between benefit attributes and cost attributes is drawn. In the benefit attribute, the highest value score is the best, while in the cost attribute the lowest value is preferred. This is because users may prefer lower data price (cost attribute), and higher data rates (benefit attribute) as an example.

0.2 Task 1: Literature Review

0.2.1 Heterogeneous Networks

Heterogeneous networks are networks made up of different Radio Access Technologies. In study [1] heterogeneous networks are desirable as users can switch connections between different access

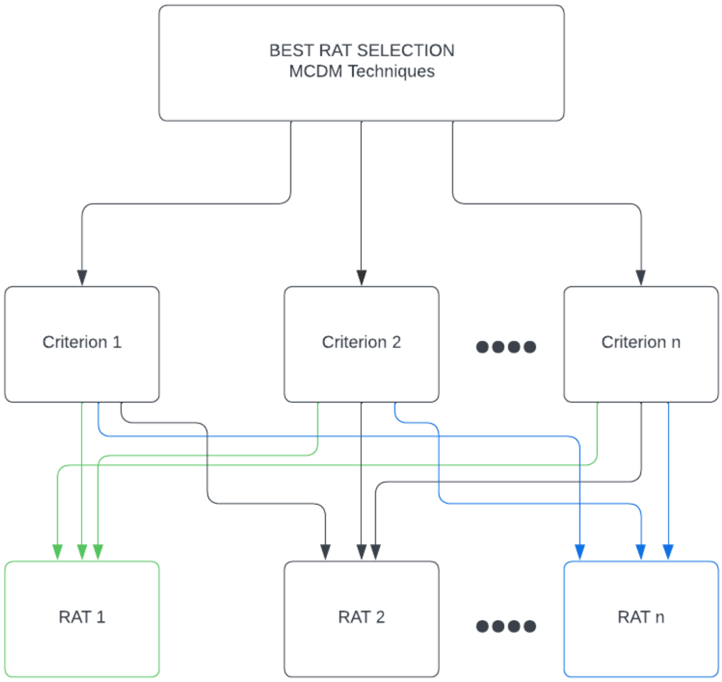

Figure 2: RAT Selection Overview

technologies to satisfy the Always Best Connected requirements. Figure 3 below shows an example of a heterogeneous network with the different access technologies used for the vertical handoff decisions [1]

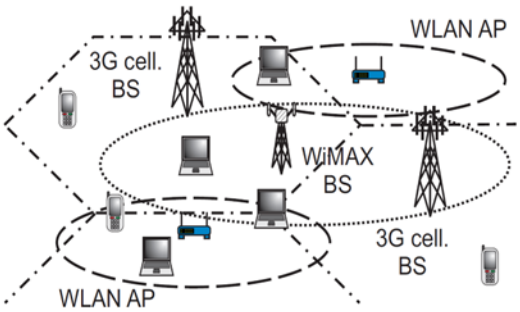

Figure 3: Heterogeneous Network Example [1]

Study [2] states that mobility management is crucial in heterogeneous networks to facilitate the seamless handoff of one user from one access technology to another.

Vertical Handoff The process of switching from one access technology to another within different networks is known as vertical handoff. In the Studies [1], [2] vertical handoff comprises of three phases: network discovery(handover information gathering), handoff decision, and handoff execution. In [2] Vertical handoff provides convenience depending on user preferences and can be initiated for this reason instead of just for connectivity. Study [2] also highlights that automation and seamlessness in network switching are two major difficulties faced in vertical handoff.

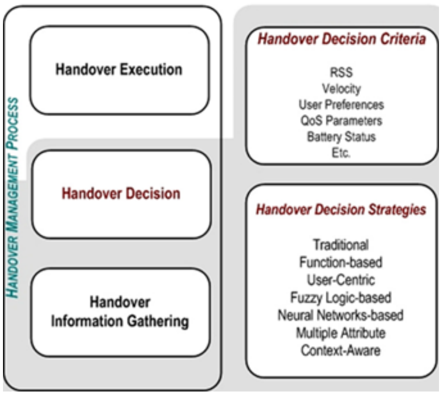

Figure 4: Handoff Management Process, Decision Criteria and Strategies [2]

Handoff can further be classified in two: Forced Handoff (depending on resource availability), and User Handoff (with user preferences being the trigger)[2]. Vertical Handoff Algorithms should be able to discern between different mobile devices accurately 'as to balance the loads of traffic in the networks' [3]

0.2.2 Multi-Criteria Decision Making

Multi-Criteria Decision making is essential as the different attributes are constantly changing with the network environment the user is in [4]. Multiple Criteria Decision Making (MCDM) is incorporated in decisions that include multiple objectives and attributes[2].' The factors/attributes can be classified as beneficial, i.e. the larger, the better, or cost, i.e. the lower, the better'[5, p. 334] criteria for handoff decisions is essential to determine the appropriate time to perform handoff and also to fulfil user preference for user centric strategies [2].

The performances of different MADM algorithms such as SAW, MEW, TOPSIS and VIKOR are reviewed and compared for voice and data connection applications [1]. SAW, VIKOR and TOPSIS are concluded to be better suited for voice due to less packet delay and jitter, while GRA and MEW are better suited to data connections due to more available bandwidth [1].

To keep up with the complexity of today's heterogenous networks, study [4] proposes a vertical handoff algorithm that incorporates a neural network model. This is for added precision in making the correct decision upon handoff.

0.3 Task 2

Creation of a Decision Matrix depends on the number of available RATs and the number of selection criteria chosen. For this investigation three selection criteria and three available RATs have been chosen. This translates into a 3x3 matrix where the rows represent the RATs and the columns represent each criteria. The Decision Matrix is shown below:

$$D = \begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{bmatrix} \tag{1}$$

0.3.1 Available RATs and Decision Criteria

Table 1: Available RATs and Decision Criteria

Available RATs	Cost (R per MB)	Datarate (Mbps)	Delay (ms)
3G	0.15	3	100
WLAN	0.19	50	60
5G	0.5	100	5

The criteria in Table 1 is selected arbitrarily as a way to illustrate the design of the Handoff algorithm. For cost and delay, the lowest value is desired and has the highest weighting, while we require the highest data rate for quality of service. Only one type of call (data connection) is considered for the RATs and they are assumed to all support this class of calls. From Table 1 the Decision matrix is:

$$D = \begin{bmatrix} 0.15 & 3 & 100 \\ 0.19 & 50 & 60 \\ 0.5 & 100 & 5 \end{bmatrix}$$

0.3.2 User Preference Weightings

For each of the available criteria, users can assign weights from 1 to 10 with 1 representing the least important criterion and 10 representing the most important criterion for the RAT-selection process. Weightings for the selection criteria are assigned to each user at random. 1000 users were selected for this case study. Weightings for the first 10 users have been shown in Table 2 below:

Table 2: User's Weights For RAT Criteria

USER	Cost (R per MB)	Datarate (Mbps)	Delay (ms)
1	6	2	6
2	10	1	10
3	10	4	10
4	4	1	1
5	9	2	3
6	9	2	1
7	7	7	7
8	1	9	5
9	3	2	5
10	1	9	5

0.4 Task 3

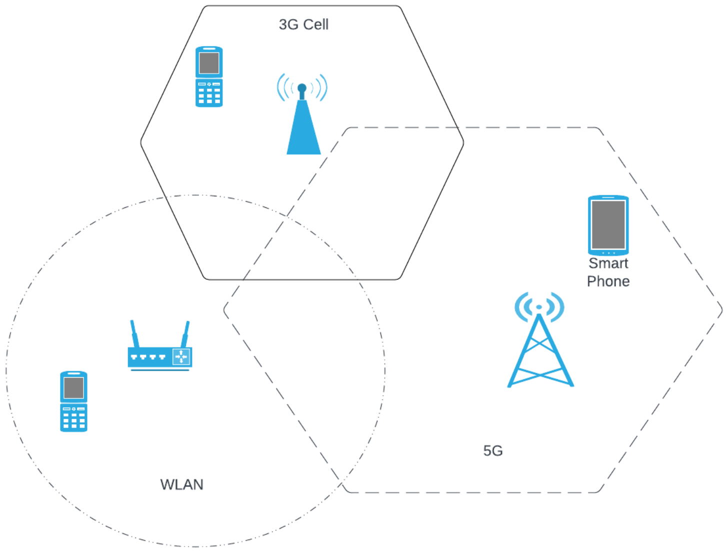

Figure 5: Heterogeneous Network To Be Evaluated

0.5 Task 4: Flowchart Showing The Procedure For RAT-selection Decisions

Figure 6 illustrates how RAT-selections decisions are made for vertical handoff calls in the heterogeneous network being investigated.

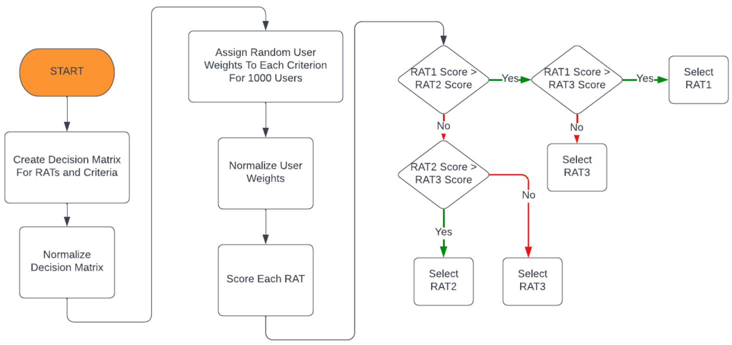

Figure 6: RAT-Selection Decision Making Flowchart

0.6 Task 5

The Normalization of the Decision Matrix is shown below:

$$D' = \begin{bmatrix} c'_{11} & c'_{12} & c'_{13} \\ c'_{21} & c'_{22} & c'_{23} \\ c'_{31} & c'_{32} & c'_{33} \end{bmatrix} \tag{2}$$

If the criterion is a cost attribute, it can be normalized as follows:

$$c'_{i,j} = \frac{min(c_{i,j})}{c_{i,j}} \tag{3}$$

Otherwise, if the criterion is a benefit attribute, it can be normalized as follows:

$$c'_{i,j} = \frac{c_{i,j}}{max(c_{i,j})} \tag{4}$$

Where i and j are the rows and columns of the matrix respectfully.

The normalized Decision Matrix becomes:

$$D' = \begin{bmatrix} 1.0 & 0.03 & 0.05 \\ 0.7895 & 0.5 & 0.0833 \\ 0.3 & 1.0 & 1.0 \end{bmatrix}$$

0.7 Task 6

To normalize the weights assigned by the users, a normalized weight vector can be established as follows:

$$W_x norm = \frac{w_x}{\sum_{n=1}^{N} w_n} \tag{5}$$

Where x represents the current weight and n is the range [1,N], the number of elements in the vector.

Scoring the preference weightings for each RAT can then be done as follows:

$$R_i = \sum_{n=1}^{N} W_n norm * c'_{i,n} \tag{6}$$

User 1 has been chosen to illustrate how their weight vector can be found using Equation 5.

$$\textbf{User 1} = \{\frac{6}{6+2+6}, \frac{2}{6+2+6}, \frac{6}{6+2+6}\}$$

$$\textbf{User 1} = \{0.4286, 0.1429, 0.4286\}$$

RAT Scoring And Selection The RAT with the highest scoring is selected and a user handoff is initiated. This means that the user is then connected to their preferred RAT. If two RATs have the same scoring, then the user will be connected to the least loaded RAT.

using User 1 as an example, Equation 6 can be used to rank each RAT as follows:

RAT 1 (3G) Scoring

$$R_1 = (1 * 0.4286) + (0.03 * 0.1429) + (0.05 * 0.4286) = 0.4543$$

RAT 2 (WLAN) Scoring

$$R_2 = (0.7895 * 0.4286) + (0.5 * 0.1429) + (0.0833 * 0.4286) = 0.4455$$

RAT 3 (5G) Scoring

$$R_3 = (0.3 * 0.4286) + (1 * 0.1429) + (1 * 0.4286) = 0.7001$$

Therefore, User 1 will pick RAT3 as it has the highest score.

0.8 Task 7: Effect Of User's Weights Assigned To RAT-Selection Criterion 1

Criterion 1 is the cost of each RAT. As the user's preferences(weightings) increase for cost, Figure 7 shows an increase in the user handoffs to the 3G RAT. This is expected as 3G has the lowest cost according to Table 1.

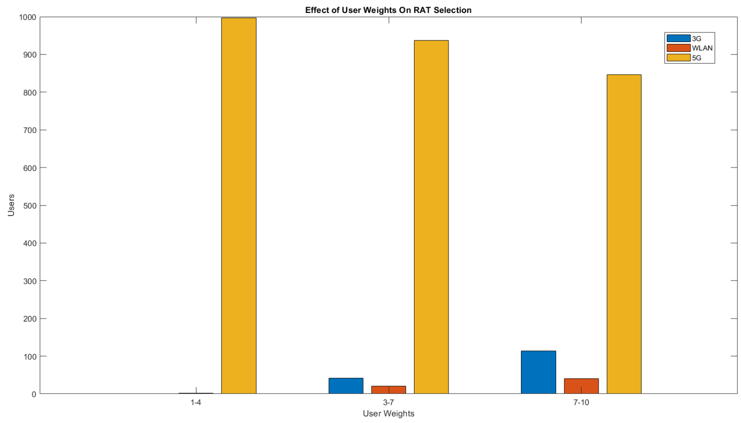

Figure 7: Effect Of User's Weights on Criterion 1

0.9 Task 8: Effect Of User's Weights Assigned To RAT-Selection Criterion 2

To study the effect of user weights where Criterion 2 (datarate) is varied, the user distribution in the figures below shows more handoff calls flocking to the 5G RAT as this has the highest datarate at 100Mbps according to Table 1 as user weighting preferences for criterion 2 increase.

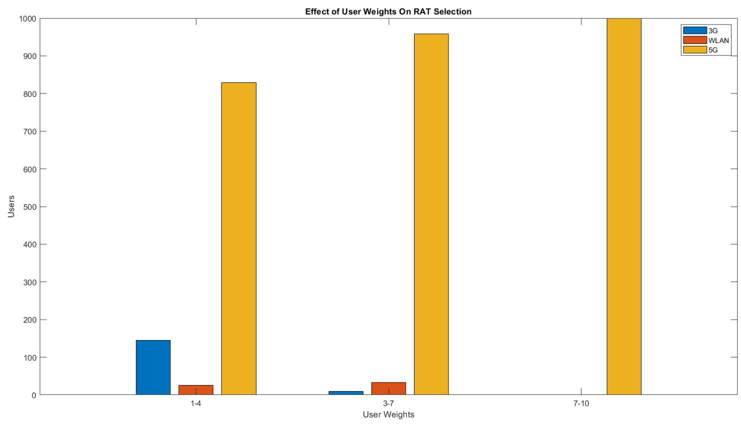

Figure 8: Effect Of User's Weights on Criterion 2

0.10 Task 9:Effect Of User’s Weights Assigned To RAT-Selection Criterion 3

To investigate the effects of Delay (criterion 3), when users prefer less delay, The figures below show the number of user handoffs to the 5G RAT increase as it has the lowest latency according to Table 1.

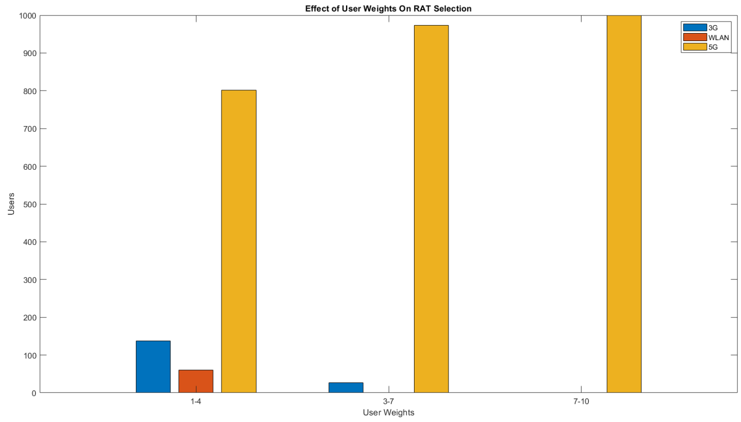

Figure 9: Effect Of User’s Weights on Criterion 3

0.11 Task 10: Conclusions

The purpose of this project was to design a vertical handoff algorithm using the multi-criteria decision-making technique.

The SAW technique was investigated with randomized user weightings for 1000 users. The algorithm was then implemented in MATLAB as shown in Appendix A. The attributes that constituted the decision-making criteria were: cost (R per MB), datarate (Mbps), and delay (latency in ms). Loading traffic of each RAT varied when a certain criterion was given greater importance over the others. This is because when vertical handoff is initiated in user-centric networks, the user is connected to the RAT with the greatest weight according to that user's preferences.

In summary, the project achieved the goals that were set out, by designing and demonstrating a Multi-Criteria Decision Making Algorithm to carry out handoff decisions for users in a heterogeneous network made up of 3 different Radio Access Technologies. The project also compared effects of user weights assigned to each RAT-selection criterion.

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Appendix A Algorithm Design For Making Handover Decisions in Heterogeneous Wireless Networks

The user defined weights are generated randomly from 1-10. The simulation is for 1000 users. The illustration below is for Criterion 1. The same can be illustrated for criterion 2 and Criterion 3. To do this, only the Criterion Ranges need to be changed in the cell below. And then the rest of the script can be re-run.

```
% create table with column names
U = table('Size',[1000,3],'VariableNames',{'cost','datarate','delay'}, 'VariableTypes',{'uint8','uint8','uint8'});


% create table with column names
U1 = table('Size',[1000,3],'VariableNames',{'cost','datarate','delay'}, 'VariableTypes',{'uint8','uint8','uint8'});

% Criterion Range [1,4]
U1.cost = randi([1,4],1000,1);%Criterion 1
U1.datarate = randi([1,10], 1000, 1);%Criterion 2
U1.delay = randi([1,10], 1000, 1);%Criterion 3
% create table with column names
U2 = table('Size',[1000,3],'VariableNames',{'cost','datarate','delay'}, 'VariableTypes',{'uint8','uint8','uint8'});

% Criterion Range [4,7]
U2.cost = randi([4,7], 1000, 1); %Criterion 1
U2.datarate = randi([1,10],1000,1); %Criterion 2
U2.delay = randi([1,10], 1000, 1); %Criterion 3

U3 = table('Size',[1000,3],'VariableNames',{'cost','datarate','delay'}, 'VariableTypes',{'uint8','uint8','uint8'});

% Criterion Range [7,10]
U3.cost = randi([7,10], 1000, 1);%Criterion 1
U3.datarate = randi([1,10], 1000, 1);%Criterion 2
U3.delay = randi([1,10],1000,1);%Criterion 3
%Convert Table To Matrix
A1 = table2array(U1);
A2 = table2array(U2);
A3 = table2array(U3);

%Empty Matrix To Use for normalization
B1 = zeros(1000,3);
```

```
B2 = zeros(1000,3);
B3 = zeros(1000,3);
```

Available RATs and RAT-selection Criteria

There are 3 available RATs namely, 3G, WLAN and 5G. Criteria to be used is Price per MB, Available Datarate, Delay

Construction Of The Decision Matrix

```
% generate random values for each term
rat_type = {'3G';'WLAN'; '5G'};
R_datarate = [3;50;100];% Mbps
R_cost = [0.15;0.19;0.5];%Cost in R per MB
R_delay = [100;60;5]; %Latency in ms

% create table with column names
R = table(rat_type, R_cost,R_datarate,R_delay);

D_rat = [R_cost R_datarate R_delay];

%Empty Matrix For Normalization
E = zeros(3,3);
```

Normalizing Data

Datarate = Benefit Attributes, Cost = Cost Attribute, Delay = Cost Attribute

```
[r_row, r_col] = size(D_rat);
[row, col] = size(A1);

%Datarate
for i = 1:r_row
   E(i,2) = D_rat(i,2) / max(D_rat(:,2));
end

%Delay
for i = 1:r_row
   E(i,3) = min(D_rat(:,3)) / D_rat(i,3);
end


%Cost
for i = 1:r_row
```

```
    E(i,1) = min(D_rat(:,1)) / D_rat(i,1);
end


%Normalize User Weights
for i = 1:row
    for j = 1:col
        B1(i,j) = A1(i,j)/sum(A3(i,:));
        B2(i,j) = A2(i,j)/sum(A3(i,:));
        B3(i,j) = A3(i,j)/sum(A3(i,:));
    end
end
```

SAW (Simple Additive Weighting)

```
% Calculate the weighted sum
s1 = zeros(row,col);
s2 = zeros(row,col);
s3 = zeros(row,col);
for i = 1:row

        %User Weights From [1-3]
        s1(i,1) = (B1(i,1)*E(1,1))+ (B1(i,2)*E(1,2)) + (B1(i,3)*E(1,3));%RAT 1 Score
        s1(i,2) = (B1(i,1)*E(2,1))+ (B1(i,2)*E(2,2)) + (B1(i,3)*E(2,3));%RAT 2 Score
        s1(i,3) = (B1(i,1)*E(3,1))+ (B1(i,2)*E(3,2)) + (B1(i,3)*E(3,3));%RAT 3 Score
        %User Weights From [3-7]
        s2(i,1) = (B2(i,1)*E(1,1))+ (B2(i,2)*E(1,2)) + (B2(i,3)*E(1,3));%RAT 1 Score
        s2(i,2) = (B2(i,1)*E(2,1))+ (B2(i,2)*E(2,2)) + (B2(i,3)*E(2,3));%RAT 2 Score
        s2(i,3) = (B2(i,1)*E(3,1))+ (B2(i,2)*E(3,2)) + (B2(i,3)*E(3,3));%RAT 3 Score
        %User Weights From [7-10]
        s3(i,1) = (B3(i,1)*E(1,1))+ (B3(i,2)*E(1,2)) + (B3(i,3)*E(1,3));%RAT 1 Score
        s3(i,2) = (B3(i,1)*E(2,1))+ (B3(i,2)*E(2,2)) + (B3(i,3)*E(2,3));%RAT 2 Score
        s3(i,3) = (B3(i,1)*E(3,1))+ (B3(i,2)*E(3,2)) + (B3(i,3)*E(3,3));%RAT 3 Score
end
```

Effect Of User Weights On RAT Selection

```
%Effect of Users Weightd [1,4] On RAT Selection For a Certain Criterion

RAT1 = 0; %RAT1 Load
RAT2 = 0;%RAT2 Load
RAT3 = 0; %RAT3 Load
```

```

for i = 1:row
    if s1(i,1) == max(s1(i,:))
        RAT1 = RAT1 +1;
    elseif s1(i,2)== max(s1(i,:))
        RAT2 = RAT2 +1;
    elseif s1(i,3) == max(s1(i,:))
        RAT3 = RAT3 +1;
    end
end

y1 = [RAT1 RAT2 RAT3];

%Effect of Users Weightd [3,7] On RAT Selection For a Certain Criterion}

RAT1 = 0; %RAT1 Load
RAT2 = 0;%RAT2 Load
RAT3 = 0; %RAT3 Load

for i = 1:row
    if s2(i,1) == max(s2(i,:))
        RAT1 = RAT1 +1;
    elseif s2(i,2)== max(s2(i,:))
        RAT2 = RAT2 +1;
    elseif s2(i,3) == max(s2(i,:))
        RAT3 = RAT3 +1;
    end
end

y2 = [RAT1 RAT2 RAT3];

%Effect of Users Weightd [7,10] On RAT Selection For a Certain Criterion}
RAT1 = 0; %RAT1 Load
RAT2 = 0;%RAT2 Load
RAT3 = 0; %RAT3 Load

for i = 1:row
    if s3(i,1) == max(s3(i,:))
        RAT1 = RAT1 +1;
    elseif s3(i,2)== max(s3(i,:))
        RAT2 = RAT2 +1;
    elseif s3(i,3) == max(s3(i,:))
        RAT3 = RAT3 +1;
```

```
    end
end

y3 = [RAT1 RAT2 RAT3];

y = [y1; y2; y3]

wRange = categorical({'1-4', '3-7', '7-10'});%Weight Ranges
wRange= reordercats(wRange,{'1-4','3-7', '7-10'});

%Plot Results
bar(wRange, y)
xlabel('User Weights')
ylabel('Users')
title("Effect of User Weights On RAT Selection")
legend('3G', 'WLAN', '5G')
```