PROJECT 1

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March 22, 2024

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Contents

Chapter 1

Task 1: Literature Review

1.1 Introduction

In heterogeneous networks (HetNets), vertical handoff decisions play a crucial role in maintaining a smooth connectivity and a enjoyable user experience. Mobile devices can connect to cellular and Wi-Fi networks, among other various Radio Access Technologies (RATs), through these networks. Where vertical handoff involves moving a user session between distinct RATs, horizontal handoff means moving these sessions within the same RAT. Vertical handoff therefore necessitates a more complex approach than the traditional single-factor RAT selection methods.

This review aimed to investigate the way in which HetNets' vertical handoff decisions can be optimised through the use of Multi-Attribute Decision Making (MADM) techniques. The review explored well established MADM methods such as the Grey Relational Analysis (GRA), Multiplicative Exponent Weighting (MEW) and Simple Additive Weighting (SAW), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). These methods vary in complexity and allows the decision-making process to factor in a variety of variables – variables such as cost, data rate, and signal strength.

Furthermore, the review explored the advancements beyond the traditional MADM approaches. It discussed research that formulated the handoff decision problem as a Generalized Assignment Problem (GAP) which aimed to maximize user utility while factoring in the capacity constraints. Decisions will become more user-centric as a result of this strategy. Additionally, in HetNets with several ongoing calls, the use of a Modified Fuzzy TOPSIS approach for group decision-making scenarios was investigated. This technique incorporated fuzzy logic to deal with the subjectivity of user preferences and network parameters, leading to an approach for RAT selection which is more holistic.

1.2 Vertical handoff decision algorithms for HetNets

Conventional techniques for RAT selection often depend on a single dominant factor (such as received power or signal strength) to make the final decision. However, in HetNets, considering multiple criteria is vital for not only optimal performance but user satisfaction as well. MADM techniques offer an organized framework for assessing and prioritizing alternatives according to several, sometimes contradictory, criteria.

In HetNets, mobile devices can connect to various RATs like cellular networks (e.g., 4G LTE, 5G) and Wi-Fi as mentioned before. Selecting the optimal RAT for each user is pivotal in ensuring a seamless connection and providing good Quality of Service (QoS). As mentioned beforee, conventional approaches often rely on a single factor however HetNets demand a more nuanced approach.

Vertical Handoff vs. Horizontal Handoff Horizontal handoff involves switching between access points within the same RAT (i.e. moving between different Wi-Fi access points). Vertical handoff refers to transition a user session will experience from one type of RAT to another (i.e. switching from cellular data to Wi-Fi). This distinction is important because different RATs have different characteristics in terms of data rate, coverage, and latency.

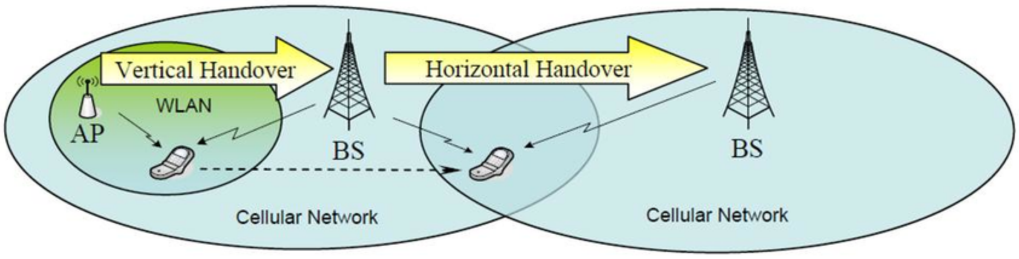

Figure 1.1: Procedure of Vertical and Horizontal Handoff [1]

The Vertical Handoff Process
The vertical handoff process can be divided into three main steps:

1. **Network Discovery:** The mobile device actively searches for available RATs in its vicinity, gathering information about signal strength, data rate, and other relevant parameters.

2. **Handoff Decision:** Based on the information collected during discovery and using MADM techniques, the network or the device itself decides whether a vertical handoff is necessary and, if so, which RAT is the most suitable option.

3. **Handoff Execution:** The actual transition from the current RAT to the new RAT takes place. This involves establishing a connection with the new network, transferring ongoing sessions, and updating routing information.

This is summarised by the following diagram showing the interconnection between these steps:

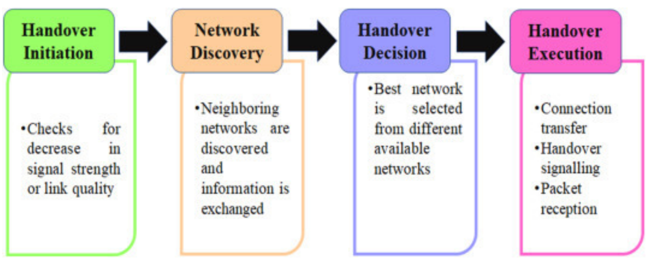

Figure 1.2: Procedure of Vertical Handoff [2]

Popular MADM Techniques for RAT Selection

Stevens-Navarro et al. (2006) [3] compare the performance of various handoff decision algorithms in HetNets, highlighting the importance of MADM techniques for such scenarios. Their study focuses on four prominent MADM techniques:

- **Simple Additive Weighting (SAW)**: Assigns weights to each attribute (like signal strength, data rate) based on its importance. The option (RAT in this case) with the highest total score (sum of weighted attribute values) is chosen [3].
- **Multiplicative Exponent Weighting (MEW)**: Similar to SAW, but it assigns weights exponentially. This can magnify the impact of highly-weighted attributes compared to SAW, potentially leading to a different preferred option.
- **Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)**: This method identifies two hypothetical solutions: an ideal positive solution (PIS) representing the best possible performance on all attributes, and an ideal negative solution (NIS) representing the worst. The RAT closest to the PIS and farthest from the NIS is considered the best choice.
- **Grey Relational Analysis (GRA)**: This technique uses 'grey relational coefficients' to analyze the similarity between the ideal scenario and the actual performance of each RAT on each attribute. The RAT with the highest similarity is chosen [3].

These techniques offer varying levels of complexity and can incorporate diverse factors into the decision-making process. While SAW and MEW provide relatively straightforward approaches, TOPSIS and GRA offer more sophisticated methods for considering trade-offs between different criteria during handoff events [3]. However, research on MADM for RAT selection has increasingly focused on techniques like TOPSIS, which offer more advanced capabilities for handling complex handoff scenarios [3].

1.3 Multi-Criteria Decision Making for Optimal Handoff Decisions in HetNets

The pivotal role of MADM techniques in RAT selection for HetNets has been established. This section will now delve deeper into the recent advancements in Multi-Criteria Decision Making (MCDM) specifically tailored for handoff scenarios within HetNets.

Beyond TOPSIS: Exploring Alternative Approaches

While TOPSIS is a well known and established MCDM technique, research is actively exploring alternative approaches for optimal handoff decisions. The paper 'Optimal Multicriteria RAT-Selection Decisions for Multiple Handoff Calls in Heterogeneous Wireless Networks' by Falowo (2016) details such advancements [4].

Falowo formulated the problem of optimal handoff decisions as a Generalized Assignment Problem (GAP) in an attempt to maximize the objective function under the constraints of call Quality of Service (QoS) requirements and available RAT capacities. The objective function measures how well the chosen combination of RATS aligns with users' preferences for the calls to be admitted, considering limitations on available resources [4].

The objective of the proposed algorithm, as stated in the paper, is to optimally assign calls to RATs [4]. This assignment aims to:

- **Maximize User Utility:** The assignment aims to maximize the total utility value experienced by the users. This utility value likely incorporates various factors like call quality, data rates, and latency, depending on user preferences and application requirements [4].
- **Capacity Constraints:** The assignment must ensure that the capacity of any chosen RAT is not exceeded. This ensures efficient network resource utilization and avoids overloading any particular RAT with excessive traffic [4].

Falowo's work advances MCDM for handoffs in HetNets with a GAP-based approach, it considers user preferences, diverse criteria, and capacity constraints [4]. This paves the way for more user-centric decisions.

1.4 Modified Fuzzy TOPSIS for Group Decision Making in RAT Selection

While the previous section explored a GAP-based approach for handoff decisions, another line of research focused on applying MCDM techniques specifically suited for group decision-making scenarios. The paper 'RAT Selection for Multiple Calls in Heterogeneous Wireless Networks using Modified Fuzzy TOPSIS Group Decision Making Technique' by Falowo et al. (2011) illustrates such approach [5].

In this work, the authors propose a fresh approach using a Modified Fuzzy TOPSIS technique for RAT selection in HetNets with multiple ongoing calls [5]. Fuzzy TOPSIS incorporates fuzzy logic to handle the inherent vagueness and subjectivity associated with the user preferences and network parameters in HetNets. This allows for a more realistic representation of user priorities and network conditions [5].

The 'modified' aspect of their approach refers to the inclusion of group decision-making capabilities. Traditional TOPSIS focuses on individual decision-makers, but Falowo et al. (2011) extend it to consider preferences from multiple users with potentially conflicting priorities for their ongoing calls [5].

Here are some key aspects of the proposed approach:

- **Multiple Call Scenarios:** The technique caters to situations where multiple calls are ongoing on a user's device, each with potentially different requirements for network resources like bandwidth or latency [5].

- **User Preferences and Network Parameters:** The approach considers both user preferences for call quality and various network parameters that impact performance, such as signal strength and data rates [5]. Fuzzy logic helps represent these factors with varying degrees of importance or certainty.
- **Group Decision-Making:** The modified TOPSIS framework allows for aggregating preferences from multiple users, leading to a more holistic decision for RAT selection that considers everyone's needs [5].

Falowo et al. (2011) highlight two key contributions in their work [5]. Firstly, they conceptualize the group-call RAT selection problem within HetNets. This problem formulation is important for understanding how to handle multiple ongoing calls with potentially conflicting needs when selecting the optimal RAT [5]. Secondly, and the focus of this review section, is their application of a Modified Fuzzy TOPSIS group decision-making technique to address this challenge [5].

By incorporating fuzzy logic and extending TOPSIS for group decision-making, Falowo et al. (2011) propose a more user-centric and adaptable approach for RAT selection in complex HetNet scenarios [5]. This section has specifically delved into the application of this Modified Fuzzy TOPSIS technique, highlighting its strengths in catering to multiple calls, user preferences, and network parameters within a group decision-making framework.

1.5 Conclusion

This review examined different vertical handoff decision algorithms for HetNets, as traditional RAT selection approaches often relied on a single dominant factor. HetNets necessitate a more sophisticated approach that considers multiple, often conflicting, criteria. Multi-Criteria Decision Making (MCDM) techniques provide a structured framework for evaluating and ranking RAT alternatives based on these criteria.

The review explored two prominent MCDM approaches: a Generalized Assignment Problem (GAP)-based formulation by Falowo (2016) that focuses on maximizing user utility while considering capacity constraints, and a Modified Fuzzy TOPSIS technique introduced by Falowo et al. (2011) that caters to scenarios with multiple ongoing calls and incorporates fuzzy logic to handle user preferences and network parameters. Both approaches offer significant advantages over traditional techniques by enabling more user-centric and adaptable handoff decisions.

Chapter 2

Task 2: Specifying Technologies and Criteria for Network Selection Algorithm with TOPSIS

2.1 Radio Access Technologies (RATs)

I have chosen the following three basic and widely used RATs for this project:

1. **Wi-Fi (WLAN):** This is the maximum data transfer capacity, expressed in Mbps (Megabits per second), that a user is allotted on a particular RAT. Greater values are preferred.
2. **2G (GSM/EDGE):** The duration of a data packet's journey from the user device to the network and back is indicated by this. It has a millisecond (ms) measurement. Delay should be minimised.
3. **4G (LTE):** Shows the amount of battery life that a device needs to keep connected to a particular RAT. Longer battery life is achieved with lower ratings.

2.2 Calls Supported by Each RAT

The following list displays the various calls which each RAT can support:

- **Wi-Fi:** Primarily supports data calls (web browsing, streaming, downloads).
- **2G:** Primarily supports voice calls (standard phone calls).
- **4G:** Supports both voice and data calls.

2.3 RAT Selection Criteria

The following list displays the selection criteria which will be used in deciding which RAT will be assigned:

1. **Allowed Bandwidth (ABW):** This represents the maxmimum amount of data transfer capacity allocated to a user on a specific RAT measured in Mbps (Megabits per second). Higher values are desirable.

2. **Delay (D):** Indicates the time it takes for data packets to travel from the user device to the network and back. Measured in milliseconds (ms). Lower delay is desirable.

3. **Power Consumption (PC):** Indicates how much battery power a device uses to maintain a connection with a specific RAT. Lower values are better for battery life.

2.4 Decision Matrix

The following table displays the decision matrix as a table:

RATs/Criteria	Allowed Bandwidth	Delay	Power Consumption
WiFi (W)	BW	DW	PW
2G (G)	BG	DG	PG
4G (L)	BL	DL	PL

Table 2.1: Decision Matrix for Network Selection

The above table was used to produce the following decision matrix:

$$\text{Decision Matrix} = \begin{array}{c} \\ \text{WiFi (W)} \\ \text{2G (G)} \\ \text{4G (L)} \end{array} \begin{array}{c} \begin{array}{ccc} \text{Allowed Bandwidth} & \text{Delay} & \text{Power Consumption} \end{array} \\ \begin{pmatrix} BW & DW & PW \\ BG & DG & PG \\ BL & DL & PL \end{pmatrix} \end{array}$$

BW, BG, BL: These represent numerical values for each criterion for WiFi. Similarly, values for 2G and 4G are represented.

The following is the decision matrix with assigned values:

$$\text{Decision Matrix} = \begin{array}{c} \\ \text{Wi-Fi (W)} \\ \text{2G (G)} \\ \text{4G (L)} \end{array} \begin{array}{c} \begin{array}{ccc} \text{ABW (Mbps)} & \text{D (ms)} & \text{PC (on a scale of 1 to 7)} \end{array} \\ \begin{pmatrix} 1000 & 30 & 1 \\ 0.384 & 500 & 2 \\ 100 & 50 & 4 \end{pmatrix} \end{array}$$

Wi-Fi here is using the 802.11ac (WiFi5), which operates at 5Ghz frequency and according to some literature can operate up to 3.47Gbps, has a latency/delay of 30ms and compared to other various technologies has the lowest power consumption [6]. For the 2G network, we are using GSM Evolution (EDGE) which has a data rate of 384kpbs, a latency of 500ms, and compared to Wi-Fi and 4G LTE, has the second highest power consumption. 4G LTE was researched and was found to have the highest power consumption out of the RATs, has a peak data rate of 100Mbps and a larency of 50ms. Various sources were used including lecture material to determine the various data rates (allowed bandwidth), delay, and power consumption for the above table.

2.5 Weights user can assign to a RAT-selection criterion

The following table displays the weightings a user can assign to any criteria.

Weight Level	**Value**
1	Ultra Low
2	Very Low
3	Low
4	Medium
5	High
6	Very High
7	Ultra High

Table 2.2: Weight Levels for RAT-Selection Criteria

Chapter 3

Task 3: Diagram of the Heterogeneous Network

The following diagram displays an illustration of how the heterogeneous network to be evaluated looks:

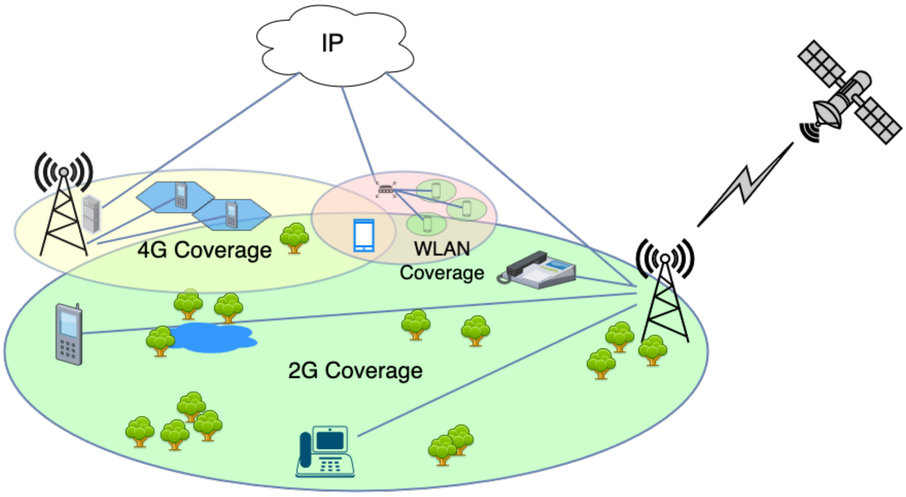

Figure 3.1: A diagram of the heterogeneous network to be evaluated.

Chapter 4

Task 4: Flowchart showing the procedure for making RAT-selection decisions

The following flowchart demonstrates the basic procedure in determining the specific Radio Access Technology (RAT) should connect to:

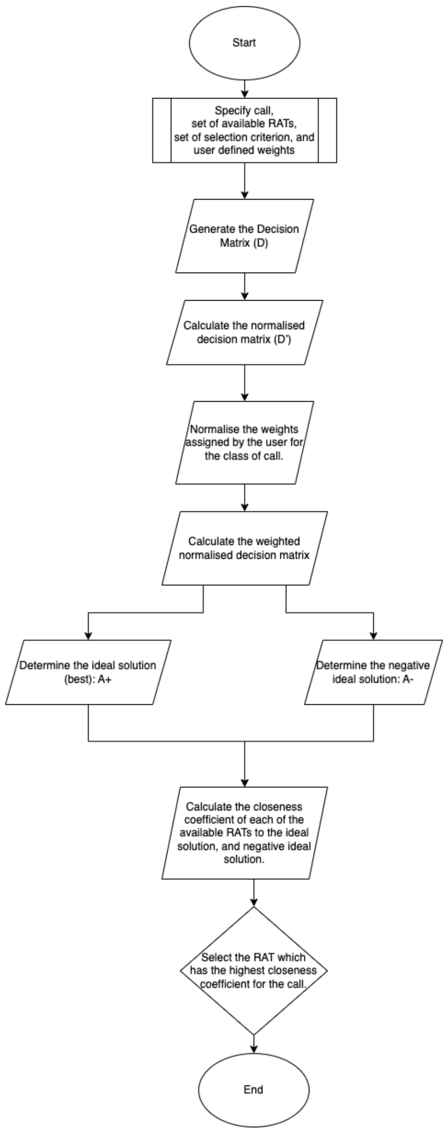

Figure 4.1: A flowchart showing the RAT-selection decisions.

Chapter 5

Task 5: Equations for normalizing the decision matrix.

The following is the equation used to normalise the decision matrix:

$$n_{ij} = \frac{m_{ij}}{\sqrt{\sum_{i=1}^{N} m_{ij}^2}} \tag{5.1}$$

Where, $i = 1, 2, ..., N$ and $j = 1, 2, ..., X$

In TOPSIS, m_{ij} represents the performance value of RAT R_i on criterion C_j, provided the decision matrix is constructed as follows:

$$\mathbf{D} = \begin{array}{c} \\ R_1 \\ R_2 \\ \vdots \\ R_N \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_X \end{array} \\ \begin{pmatrix} m_{11} & m_{12} & \cdots & m_{1X} \\ m_{21} & m_{22} & \cdots & m_{2X} \\ \vdots & \vdots & \ddots & \vdots \\ m_{N1} & m_{N2} & \cdots & m_{NX} \end{pmatrix} \end{array}$$

Where, $R_1, R_2, ..., R_N$ are the available RATs and $c_1, c_2, ..., c_X$ represent the criteria for each RAT.

The resulting normalised decision matrix D' is as follows, where n' is the normalised performance rating of RAT, R_i on criteria c_j:

$$\mathbf{D'} = \begin{bmatrix} n'_{11} & n'_{12} & \cdots & n'_{1X} \\ n'_{21} & n'_{22} & \cdots & n'_{2X} \\ \vdots & \vdots & \ddots & \vdots \\ n'_{N1} & n'_{N2} & \cdots & n'_{NX} \end{bmatrix} \tag{5.2}$$

The above equation 5.1 was used to determine the columns of the normalised decision matrix as follows:

$$
\begin{aligned}
n_{11} &= \frac{1000}{\sqrt{1010000.15}} \approx 0.995 \\
n_{21} &= \frac{0.384}{\sqrt{1010000.15}} \approx 0.0004 \\
n_{31} &= \frac{100}{\sqrt{1010000.15}} \approx 0.0995 \\
n_{12} &= \frac{30}{\sqrt{253400}} \approx 0.0596 \\
n_{22} &= \frac{500}{\sqrt{253400}} \approx 0.993 \\
n_{32} &= \frac{50}{\sqrt{253400}} \approx 0.0993 \\
n_{13} &= \frac{1}{\sqrt{21}} \approx 0.2182 \\
n_{23} &= \frac{2}{\sqrt{21}} \approx 0.4364 \\
n_{33} &= \frac{4}{\sqrt{21}} \approx 0.8729
\end{aligned}
$$

The values from the decision matrix were used to determine the above values. The normalised decision matrix can be constructed as follows:

$$
\begin{array}{c}
\\
\mathbf{D}' =
\end{array}
\begin{array}{c}
\\
\mathrm{W} \\ \mathrm{G} \\ \mathrm{L}
\end{array}
\begin{array}{c}
\begin{array}{ccc} \text{ABW (Mbps)} & \text{D (ms)} & \text{PC (scale from 1 to 7)} \end{array} \\
\begin{pmatrix}
0.995 & 0.0596 & 0.2182 \\
0.0004 & 0.993 & 0.4364 \\
0.0995 & 0.0993 & 0.8729
\end{pmatrix}
\end{array}
$$

Chapter 6

Task 6: Equations for ranking RATs for new & vertical handoff

6.0.1 Calculating the normalised weights

The weighing vector, $\mathbf{W_i}$ represents the relative importance of the criteria to user i, and it is given as:

$$\mathbf{W} = \{w_1, w_2, \ldots, w_X\} \tag{6.1}$$

The weighing vector is normalised as follows:

$$\hat{\mathbf{W}} = \{\hat{\mathbf{w}}_\mathbf{1}, \hat{\mathbf{w}}_\mathbf{2}, \ldots, \hat{\mathbf{w}}_\mathbf{X}\} \tag{6.2}$$

$$\hat{\mathbf{w}}_\mathbf{v} = \frac{w_v}{\sum_{u=1}^{X} w_u} \tag{6.3}$$

Where v has the following properties:

$$v = \{1, 2, \ldots, X\} \tag{6.4}$$

Example for normalising weights

The above concept will be understood better by using the following example, provided the user has the following weights:

$$w_1 = 4 \text{ for ABW (Mbps)}$$
$$w_2 = 6 \text{ for D (ms)}$$
$$w_3 = 3 \text{ for PC (scale from 1 to 7)}$$

Step 1: Calculate the sum of all weights:

$$\text{Sum of weights} = w_1 + w_2 + w_3 = 4 + 6 + 3 = 13$$

Step 2: Normalise each weight using equation 6.3:

$$\hat{w}_1 = \frac{w_1}{\text{Sum of weights}} = \frac{4}{13}$$

$$\hat{w}_2 = \frac{w_2}{\text{Sum of weights}} = \frac{6}{13}$$

$$\hat{w}_3 = \frac{w_3}{\text{Sum of weights}} = \frac{3}{13}$$

Step 3: Calculate the normalised weights:

$$\hat{w}_1 = \frac{4}{13} \approx 0.3077$$

$$\hat{w}_2 = \frac{6}{13} \approx 0.4615$$

$$\hat{w}_3 = \frac{3}{13} \approx 0.2308$$

Therefore we have the following normalised weights:

$$\hat{\mathbf{W}} = \{0.3077, 0.4615, 0.2308\} \tag{6.5}$$

6.0.2 Calculate the weighted normalised decision matrix

$$\mathbf{H} = \begin{array}{c} \\ R_1 \\ R_2 \\ \vdots \\ R_N \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_X \end{array} \\ \begin{pmatrix} h_{11} & h_{12} & \cdots & h_{1X} \\ h_{21} & h_{22} & \cdots & h_{2X} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N1} & h_{N2} & \cdots & h_{NX} \end{pmatrix} \end{array}$$

Where, $R_1, R_2, ..., R_N$ are the available RATs and $c_1, c_2, ..., c_X$ represent the criteria for each RAT. Which has the following properties:

$$h_{j,u} = \hat{\mathbf{W}} \times \hat{m}_{i,j} \quad \forall i \in \{1, \ldots, N\},\ j \in \{1, \ldots, X\} \tag{6.6}$$

Example for calculating the weighted normalised decision matrix

To calculate the weighted normalised decision matrix **H**, each element of the normalised decision matrix **D′** is multiplied by the corresponding element of the normalised weights vector $\hat{\mathbf{W}}$.

Given:

$$\hat{\mathbf{W}} = \{0.3077, 0.4615, 0.2308\}$$

And the normalised decision matrix:

$$\mathbf{D}' = \begin{array}{c} \\ \mathrm{W} \\ \mathrm{G} \\ \mathrm{L} \end{array} \begin{array}{c} \begin{array}{ccc} \text{ABW (Mbps)} & \text{D (ms)} & \text{PC (scale from 1 to 7} \end{array} \\ \begin{pmatrix} 0.995 & 0.0596 & 0.2182 \\ 0.0004 & 0.993 & 0.4364 \\ 0.0995 & 0.0993 & 0.8729 \end{pmatrix} \end{array}$$

The element-wise multiplication yields the following weighted normalised decision matrix **H**:

$$\mathbf{H} = \begin{array}{c} \\ \mathrm{W} \\ \mathrm{G} \\ \mathrm{L} \end{array} \begin{array}{c} \begin{array}{ccc} \text{ABW (Mbps)} & \text{D (ms)} & \text{PC (scale from 1 to 7)} \end{array} \\ \begin{pmatrix} 0.3062 & 0.0275 & 0.0511 \\ 0.00012 & 0.4583 & 0.1007 \\ 0.0306 & 0.04583 & 0.2014 \end{pmatrix} \end{array}$$

6.0.3 Determine the positive and negative ideal solution

In the following, A denotes the set of elements in the weighted normalised decision matrix above. A+ denotes all those associated with the ideal solution and A- is associated with the negative ideal solutions.

$$\text{Ideal Solution (A+)}: \quad h_j^+ = \begin{cases} \max\limits_{j \in R} h_{ju} & \text{if } j \in C' \\ \min\limits_{j \in R} h_{ju} & \text{if } j \in C'' \end{cases} \tag{6.7}$$

$$\text{Negative Ideal Solution (A-)}: \quad h_j^- = \begin{cases} \min\limits_{j \in R} h_{ju} & \text{if } j \in C' \\ \max\limits_{j \in R} h_{ju} & \text{if } j \in C'' \end{cases} \tag{6.8}$$

Where `C'` is the set of benefit criteria, and `C"` is the set of the negative criteria. Note that `C = C' + C"`.

Example for calculating the ideal solutions

To calculate A^+ and A^- using the given weighted normalised decision matrix **H**, we follow these steps:

1. Identify the criteria sets C' and C'' based on whether they represent maximization or minimization criteria.

For maximization criteria:

$$C' = \{\text{ABW}\}$$

For minimization criteria:

$$C'' = \{\text{D}, \text{PC}\}$$

This is because bandwidth should be maximized, while delay and power consumption should be minimized.

2. Calculate A^+:

$$h_j^+ = \begin{cases} \max\limits_{j \in R} h_{ij} & \text{if } j \in C' \\ \min\limits_{j \in R} h_{ij} & \text{if } j \in C'' \end{cases}$$

For the criteria in C':

$$h_{\text{W}}^+ = \max\{0.3062, 0.00012, 0.0306\} = 0.3062$$

For the criteria in C'':

$$h_{\text{G}}^+ = \min\{0.0275, 0.4583, 0.04583\} = 0.0275$$

$$h_{\text{L}}^+ = \min\{0.0511, 0.1007, 0.2014\} = 0.0511$$

3. Calculate A^-:

$$h_j^- = \begin{cases} \min\limits_{j \in R} h_{ij} & \text{if } j \in C' \\ \max\limits_{j \in R} h_{ij} & \text{if } j \in C'' \end{cases}$$

For the criteria in C':

$$h_{\text{W}}^- = \min\{0.3062, 0.00012, 0.0306\} = 0.00012$$

For the criteria in C'':

$$h_{\text{G}}^- = \max\{0.0275, 0.4583, 0.04583\} = 0.4583$$

$$h_{\text{L}}^- = \max\{0.0511, 0.1007, 0.2014\} = 0.2014$$

These values represent the ideal and negative ideal solutions for the considered criteria.

6.0.4 Calculating closeness coefficient and determining optimal RAT

TOPSIS identifies the best alternative (RAT) by finding the one closest to a scenario where all criteria are perfect (ideal solution) and farthest from a scenario where all criteria are the worst (negative ideal solution).

$$d_j^+ = \sqrt{\sum_{u=1}^{X} (h_{j,u} - h_j^*)^2} \quad \text{for } j = 1, 2, \ldots, N \tag{6.9}$$

$$d_j^- = \sqrt{\sum_{u=1}^{X} (h_{j,u} - h_j^-)^2} \quad \text{for } j = 1, 2, \ldots, N \tag{6.10}$$

In the above, h_j^* represents the positive ideal solution and h_j^- represents the negative ideal solution. The closeness coefficient is determined using the following equation:

$$f^j = \frac{d_j^-}{d_j^- + d_j^+} \quad \forall j = 1, 2, \ldots, N \tag{6.11}$$

Where f^j denotes the closeness coefficient.

Example for closeness coefficient calculation

We have the following for the Ideal Solution:

$$A^+ = \{0.3062, 0.0275, 0.0511\}$$

We also have the following for the Negative Ideal Solution:

$$A^- = \{0.00012, 0.4583, 0.1007\}$$

Using these values, we can calculate d_j^+ and d_j^- for each alternative j:

$$d_j^+ = \sqrt{\sum_{u=1}^{X} (h_{j,u} - h_u^*)^2}$$

$$d_j^- = \sqrt{\sum_{u=1}^{X} (h_{j,u} - h_u^-)^2}$$

Then, we can use these values to calculate the closeness coefficient f^j for each alternative.

We use the above to determine the following:
For the RAT W (which corresponds to the first row):

$$d(\text{W}, A^+) = \sqrt{(0.3062 - 0.3062)^2 + (0.0275 - 0.0275)^2 + (0.0511 - 0.0511)^2} = 0$$

$$d(\mathrm{W}, A^-) = \sqrt{(0.3062 - 0.00012)^2 + (0.0275 - 0.4583)^2 + (0.0511 - 0.1007)^2} \approx 0.5307$$

For the RAT G (which corresponds to the second row):

$$d(\mathrm{G}, A^+) = \sqrt{(0.00012 - 0.3062)^2 + (0.4583 - 0.0275)^2 + (0.1007 - 0.0511)^2} \approx 0.5307$$

$$d(\mathrm{G}, A^-) = \sqrt{(0.00012 - 0.00012)^2 + (0.4583 - 0.4583)^2 + (0.1007 - 0.1007)^2} = 0$$

For the RAT L (which corresponds to the third row):

$$d(\mathrm{L}, A^+) = \sqrt{(0.0306 - 0.3062)^2 + (0.04583 - 0.0275)^2 + (0.2014 - 0.0511)^2} \approx 0.3145$$

$$d(\mathrm{L}, A^-) = \sqrt{(0.0306 - 0.00012)^2 + (0.04583 - 0.4583)^2 + (0.2014 - 0.1007)^2} \approx 0.4257$$

Based on the above and using the closness coefficient formula, we can use the information to calculate the following:

For the RAT W:

$$C^*(\mathrm{W}) = \frac{0.5307}{0 + 0.5307} \approx 1$$

For the RAT G:

$$C^*(\mathrm{G}) = \frac{0}{0.5307 + 0} \approx 0$$

For the RAT L:

$$C^*(\mathrm{L}) = \frac{0.4257}{0.3145 + 0.4257} \approx 0.575$$

6.0.5 Selection of RAT

Select the Radio Access Technology (RAT) that exhibits the highest closeness coefficient with respect to the ideal and negative ideal solutions, indicating its optimal proximity to the desired criteria and farthest distance from undesirable criteria for the call.

Example of selection a RAT

Based on the closeness coefficients above, Wi-Fi would be the most applicable RAT since it has the highest closeness coefficient of 1.

Chapter 7

Task 7: Test of Criterion 1 on RAT Selection

7.1 Setup of the code

To investigate how users' weights affect the RAT selection process for the first criterion a Python script was created which utilises the TOPSIS method described in previous sections. The script simulates the selection for each RAT by a 100 users for each weight level.

The following setup for the simulation was used:

- **Decision matrix:** The performance attributes (Allowed Bandwidth, Delay, and Power Consumption) of each RAT (Wi-Fi, 2G, and 4G) are presented in the form of a decision matrix.
- **Weight levels:** The weight assigned to be assigned to the first RAT-selection criterion was varied across different levels (1 to 7) to observe its effect on RAT selection.
- **Benefit and Cost Criteria:** The criteria for each performance attribute was defined as either benefit (where a higher value is preferred) or cost (where a lower value is preferred).
- **Number of users:** We simulated RAT selection for 100 users to observe the overall trend.

The Python script follows the method as described in previous sections however it performs multiple iterations and stores the weights and normalised weights in a CSV file. Additionally, a bar graph is produced to illustrate the effect of weight assignment on RAT-selection decisions.

7.2 Simulation Results

This section explores how user preferences for a specific RAT selection factor influence the overall decision. We analyse data generated by a Python script that simulates RAT selection for 700 different user weight configurations.

The table below shows a sample of these configurations. Each row represents a weight assigned to three key factors: Allowed Bandwidth (ABW), Delay (D), and Power Consumption (PC). The weight determines the importance a user places on each factor when choosing a connection.

For example, the first two rows show scenarios where all users prioritize Allowed Bandwidth (weight of 1). Subsequent rows depict variations in user preferences, with each set of 100 users representing a different balance between the three factors.

Note: This table displays only a selection of the 700 total weight configurations used in the simulation.

Table 7.1: Selected Weights for Each Weight Level (First Criterion: Allowed Bandwidth)

Weight ABW	Weight D	Weight PC
1	2	6
1	6	6
2	1	6
2	6	2
3	2	5
3	5	6
4	2	7
4	7	4
5	6	2
5	7	6
6	1	2
6	7	4
7	5	3
7	5	1

The normalisation process plays a crucial role in standardising the weights assigned to each criterion for RAT-selection decisions. After defining the weights for each criterion, the next step involves normalization to ensure that the weights are on a comparable scale. This is achieved by dividing each weight by the sum of all weights assigned across the criteria. The resultant normalised weights represent the relative importance of each criterion in the decision-making process. The subsequent table, titled 'normalised Weights for Each Criterion,' showcases the normalised weights for the Allowed Bandwidth (ABW), Delay (D), and Power Consumption (PC) criteria. These normalised weights were derived from the previously presented weights table and were utilized to troubleshoot the RAT-selection process. By analyzing the normalised weights alongside the selection outcomes, discrepancies and potential biases in the decision-making process could be identified and addressed effectively.

Table 7.2: Normalised Weights for Each Criterion

Weight ABW	Weight D	Weight PC
0.1	0.3	0.6
0.25	0.25	0.5
0.1	0.7	0.2
0.2	0.2	0.6
0.1	0.6	0.3
0.6	0.2	0.2
0.3	0.1	0.6
0.6	0.2	0.2
0.3	0.1	0.6
0.3	0.4	0.3
0.3	0.5	0.2
0.5	0.3	0.2
0.3125	0.4375	0.25
0.5	0.3	0.2

The following table displays the effect of weight on RAT selection. The table consists of four columns: Weight, RAT_W, RAT_G, and RAT_L. Each row represents a different weight level along with the corresponding count of RAT_W, RAT_G, and RAT_L selections.

Table 7.3: Effect of Weight on RAT Selection

Weight	RAT_W	RAT_G	RAT_L
1	95	5	0
2	100	0	0
3	100	0	0
4	100	0	0
5	100	0	0
6	100	0	0
7	100	0	0

The following bar graph illustrates the effect of varying the weight assigned to the first RAT-selection criterion, which was highlighted in Table 7.3, namely the allowed bandwidth (ABW), on RAT-selection decisions. Each bar represents a different weight level ranging from 1 to 7. As depicted in the graph, when the weight assigned to ABW is 1, the majority of users (95 out of 100) are directed towards Wi-Fi (RAT_W), while a small fraction (5 out of 100) are directed towards 2G (RAT_G), and none towards 4G (RAT_L). As the weight on ABW increases, the dominance of Wi-Fi in RAT selection persists, with 100% of users being directed to Wi-Fi for weight levels 2 through 7. This trend indicates that the selection process prioritizes Wi-Fi over other RATs as the weight on ABW increases, emphasizing the importance of bandwidth in the decision-making process for RAT selection in heterogeneous wireless networks.

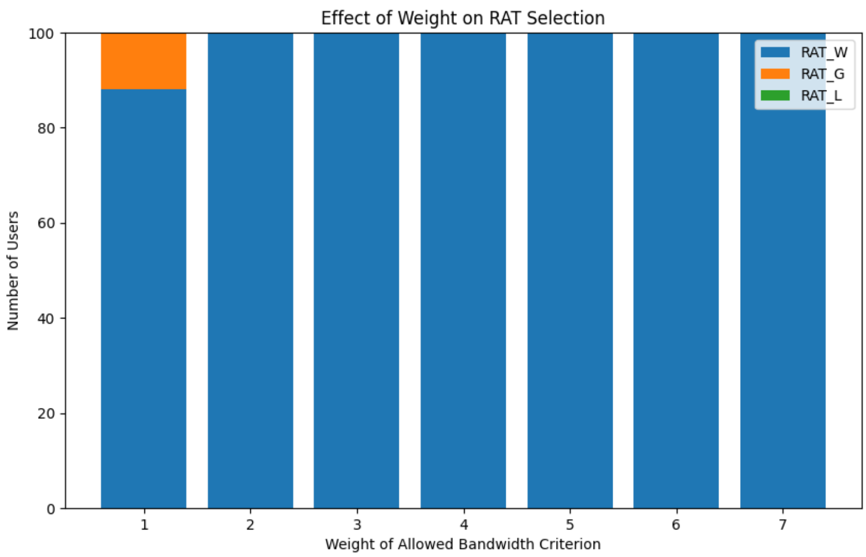

Figure 7.1: Effect of Weight on RAT Selection for Criterion 1

The consistent selection of Wi-Fi (RAT W) across all tests can be attributed to the calculation of the closeness coefficient in the code. This coefficient is computed based on the Euclidean distances to the ideal and negative ideal solutions, ultimately guiding the selection process. In the decision matrix, Wi-Fi exhibits favourable attributes, with higher values for allowed bandwidth (1000.0) and lower values for delay (30.0) and power consumption (1.0). These attributes contribute to a higher closeness coefficient for Wi-Fi during the selection process.

Furthermore, the weights assigned to each criterion also influence the selection outcome. A higher weight assigned to allowed bandwidth favours Wi-Fi even more, given its superior bandwidth compared to other RATs. Similarly, higher weights for delay and power consumption also favour Wi-Fi, as it demonstrates better performance in these criteria. Consequently, the consistent selection of Wi-Fi in majority of the tests results from a combination of favourable attributes in the decision matrix and the weights assigned to each criterion.

In the initial test with a constant weight for allowed bandwidth, the selection of some users for RAT G (2G) can be attributed to the random assignment of weights to the delay and power consumption criteria. Each user in the simulation receives randomly assigned weights for these criteria, even when the weight for allowed bandwidth remains constant. Consequently, if the weights for power consumption and delay are significantly higher than the weight for allowed bandwidth, they can disproportionately influence RAT selection. Despite 2G having lower bandwidth (0.384) and higher delay (500.0) compared to Wi-Fi, its relatively lower power consumption may make it a favourable choice when the weight for power consumption is high enough to offset its low bandwidth and high delay. Therefore, the selection of RAT G in this scenario reflects the combined influence of the random assignment of weights to criteria and the specific values in the decision matrix, which can significantly impact the RAT selection process. As seen, if the weights for allowed bandwidth and delay are low enough, and the weight for power consumption is high enough, then it makes sense why RAT G was chosen.

Examining the impact of variations in the decision matrix is imperative to grasp the nuanced interplay between the weights assigned to criteria and the inherent characteristics of each RAT. It's essential to acknowledge that the decision matrix used in this study was biased towards Wi-Fi, reflecting real-world performance data. While this bias may have influenced the results, it underscores the importance of investigating how a decision matrix with favourable characteristics for each RAT would respond to varying weights. In an ideal scenario, such a decision matrix would provide a clearer understanding of how different weight distributions affect RAT selection outcomes. By simulating scenarios where each RAT possesses favourable criteria, researchers can gain deeper insights into the intricate dynamics of heterogeneous wireless networks and better discern the impact of weight assignments on RAT selection.

Furthermore, the selection criteria for each RAT also play a crucial role in understanding the impact of weights on RAT selection. In this study, Wi-Fi was chosen as the preferred RAT due to its numerous favourable characteristics for the selected criteria. However, if other RATs were included in the analysis with different sets of criteria, the effect of weights on RAT selection could vary significantly. Investigating the influence of weights on RAT selection across a broader range of criteria and RATs would provide a more comprehensive understanding of the decision-making process in heterogeneous wireless networks.

Chapter 8

Task 8: Test of Criterion 2 on RAT Selection

8.1 Setup of the code

For the evaluation of the effect of the users' weight assigned to the second RAT-selection criterion on RAT-selection decisions, we have modified the existing simulation code used in the previous task. This modification allows us to investigate how varying weights for the second criterion impact RAT selection in new or vertical handoff calls within a heterogeneous wireless network. The simulation script, based on the TOPSIS method, remains the same, with adjustments made to reflect the new focus on the second selection criterion. This approach enables us to build upon our previous findings and gain further insights into the influence of weight distribution on RAT selection decisions.

8.2 Simulation Results

In this section, we continue our investigation into the dynamics of RAT-selection decisions within a heterogeneous wireless network by evaluating the impact of varying weights assigned to the second RAT-selection criterion, which in this case is delay. Unlike the previous task, where we focused on the weights assigned to the first criterion (Allowed Bandwidth), the weights assigned to other criteria remain randomized. Our objective is to assess how changes in the weight assigned to delay influence RAT-selection outcomes. To achieve this, we utilize the same simulation framework with modifications to the weight configurations, focusing solely on variations in the weight assigned to delay while keeping the weights for the other criteria randomized. The resulting data provides insights into the sensitivity of RAT-selection decisions to variations in the weighting of delay, shedding light on the factors that drive RAT selection in real-world scenarios.

In the following updated table, we present a selection of weights assigned to each criterion for RAT-selection decisions. Unlike the previous table, Table 7.1 which focused on varying weights for the first RAT-selection criterion, this table highlights the variation in weights for the second criterion, delay. Each row corresponds to a unique set of weights, with two selections made for each weight level, providing insight into the impact of weight variation on RAT selection decisions. It is important to note that these are a subset of 700 weights, there are 100 users for each weight level for testing.

Table 8.1: Selected Weights for Each Weight Level (Second Criterion: Delay)

Weight ABW	Weight D	Weight PC
2	1	5
5	1	3
7	2	6
1	2	7
6	3	1
1	3	7
1	4	5
7	4	7
6	5	2
5	5	5
5	6	3
7	6	2
6	7	7
3	7	7

In the subsequent table, we present the normalised weights for each criterion used in the RAT-selection decisions. This process ensures that the weights assigned to different criteria are on a comparable scale, facilitating a deeper understanding of the decision-making process. Again, note this is a subset of 700 normalised weights.

Table 8.2: Normalised Weights for Each Criterion

Weight ABW	Weight D	Weight PC
0.3	0.1	0.6
0.556	0.111	0.333
0.571	0.143	0.286
0.6	0.1	0.3
0.5	0.071	0.429
0.5	0.125	0.375
0.333	0.111	0.556
0.5	0.125	0.375
0.286	0.143	0.571
0.7	0.1	0.2
0.375	0.125	0.5
0.5	0.1	0.4
0.5	0.25	0.25
0.571	0.143	0.286

The following table consists of 4 columns, the first representing the weight applied to the criterion under test and the other 3 columns representing how many users were selected for each RAT.

Table 8.3: Effect of Weight on RAT Selection

Weight	RAT_W	RAT_G	RAT_L
1	100	0	0
2	100	0	0
3	100	0	0
4	100	0	0
5	100	0	0
6	100	0	0
7	100	0	0

The following bar graph illustrates the effect of varying the weight assigned to the second RAT-selection criterion, namely delay, on RAT-selection decisions. Each bar represents a different weight level ranging from 1 to 7. As observed in the graph, regardless of the weight assigned to delay, all users are consistently directed towards Wi-Fi (RAT_W). This indicates a strong preference for Wi-Fi across all weight levels for delay, highlighting its predominant role in RAT selection decisions in heterogeneous wireless networks.

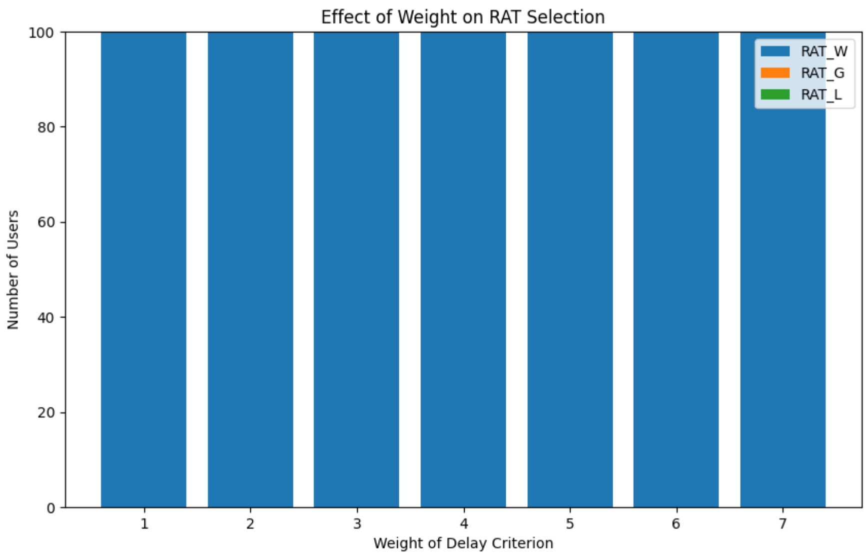

Figure 8.1: Effect of Weight on RAT Selection for Delay Criterion

The consistent selection of Wi-Fi (RAT W) across all tests echoes the influence of its favourable delay characteristics, as evident in the decision matrix. With lower delay values, Wi-Fi consistently garners a higher closeness coefficient during the selection process. However, akin to the previous test, this study's reliance on real-world performance data and the inherent bias towards Wi-Fi in the decision matrix might have influenced the results. Despite this bias, the findings underscore the critical role of delay in guiding RAT selection decisions.

Moreover, the study's focus on Wi-Fi as the preferred RAT due to its advantageous delay attributes highlights the need for broader investigation. Exploring how different RATs with varying delay criteria respond to diverse weight distributions could provide deeper insights into the intricacies of RAT selection. Such analyses could mitigate the influence of biases inherent in decision matrices biased towards specific RATs and real-world performance data. By simulating scenarios where each RAT possesses favourable delay criteria, researchers can gain a nuanced understanding of how weight assignments impact RAT selection outcomes across heterogeneous wireless networks.

Chapter 9

Task 9: Test of Criterion 3 on RAT Selection

9.1 Setup of the code

To explore the impact of users' weight assigned to the third RAT-selection criterion on RAT-selection decisions, we've adapted our simulation code from Task 7. This modification allows us to delve into how varying weights for the third criterion influence RAT selection in new or vertical handoff calls across a heterogeneous wireless network. While the simulation script retains its foundation in the TOPSIS method, we've fine-tuned it to spotlight the third selection criterion. By taking this approach, we aim to extend our understanding beyond the previous findings, offering another insight into the interplay between weight distribution and RAT selection outcomes.

9.2 Simulation Results

In this section, we extend our inquiry into the intricacies of RAT-selection decisions by examining the effects of fluctuating weights assigned to the third RAT-selection criterion. Unlike our previous investigation, which centered on the second criterion (Delay), we now turn our attention to the weight assigned to the third criterion, which represents the factor of power consumption. While the weights assigned to other criteria remain randomized, our focus is solely on evaluating the impact of changes in the weight assigned to this criterion on RAT-selection outcomes. Leveraging the same simulation framework with tailored adjustments to the weight configurations, we isolate the variations in the weight assigned to the third criterion. This approach allows us to glean insights into the responsiveness of RAT-selection decisions to alterations in the weighting of this criterion, providing valuable perspectives on the underlying drivers of RAT selection in practical scenarios.

In the following table, we present a curated selection of weights assigned to each criterion for RAT-selection decisions in a simulated heterogeneous wireless network environment. In contrast to the previous Table 8.1, which focused on the variability of weights for the second RAT-selection criterion, this table sheds light on the fluctuations in weights for the third criterion, power consumption. Each row corresponds to a distinct set of weights, with two selections made for each weight level, providing valuable insights into the repercussions of weight variation on RAT selection decisions. It's noteworthy that these weights represent a subset of the total 700 configurations tested, with 100 users assigned to each weight level for rigorous evaluation.

Table 9.1: Selected Weights for Each Weight Level (Third Criterion: Power Consumption)

Weight ABW	**Weight D**	**Weight PC**
2	1	1
7	4	1
7	3	2
6	2	2
1	7	3
2	4	3
2	4	4
5	2	4
1	2	5
3	1	5
1	7	6
6	6	6
1	2	7
4	7	7

In the following table, we provide the normalised weights for each criterion employed in the RAT-selection decisions. Normalisation of these weights ensures that the assigned values across different criteria are on a comparable scale, thereby enhancing clarity in the decision-making process. It's important to note that this table represents only a subset of the 700 normalised weights utilised in the analysis.

Table 9.2: Normalised Weights for Each Criterion (Criterion 3: Power Consumption)

Weight ABW	Weight D	Weight PC
0.125 0.25	0.75 0.625	0.125 0.125
0.2 0.375	0.7 0.5	0.1 0.125
0.3 0.4	0.6 0.5	0.1 0.1
0.3 0.5	0.6 0.25	0.1 0.25
0.6 0.5	0.2 0.375	0.2 0.125
0.25 0.5	0.625 0.4	0.125 0.1
0.625 0.25	0.25 0.5	0.125 0.25

The following table displays the effect of weight on RAT selection. The table consists of four columns: Weight, RAT_W, RAT_G, and RAT_L. Each row represents a different weight level along with the corresponding count of RAT_W, RAT_G, and RAT_L selections.

Table 9.3: Effect of Weight on RAT Selection (Criterion 3: Power Consumption)

Weight	RAT_W	RAT_G	RAT_L
1	100	0	0
2	100	0	0
3	100	0	0
4	100	0	0
5	100	0	0
6	100	0	0
7	100	0	0

In the accompanying bar chart, we visualize the influence of adjusting the weight attributed to the third RAT-selection criterion, which in this case is power consumption, on the outcomes of RAT selection. Each bar in the chart corresponds to a specific weight level, ranging from 1 to 7. Interestingly, our findings reveal a consistent pattern where all users are directed towards Wi-Fi (RAT_W) regardless of the weight assigned to power consumption. This suggests a persistent preference for Wi-Fi across various weight levels for power consumption, underscoring its dominant role in driving RAT selection decisions within heterogeneous wireless networks.

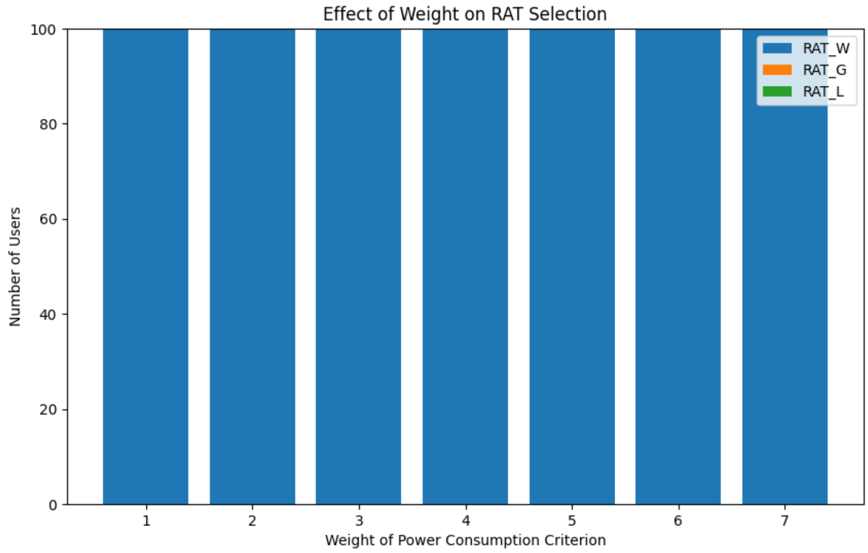

Figure 9.1: Effect of varying the weight assigned to the third RAT-selection criterion (Power Consumption) on RAT-selection decisions

In contrast to previous analyses, the prevalence of Wi-Fi (RAT W) selections across all test iterations speaks volumes about the pronounced advantage it enjoys in terms of power consumption within the decision matrix. With Wi-Fi consistently exhibiting the lowest power consumption values, it naturally accrues higher closeness coefficients during the selection process. However, the randomized assignment of weights to the other criteria, namely bandwidth and delay, introduces an element of randomness into the process. Despite this variability, the overwhelming preference for Wi-Fi suggests a significant disparity in performance across the evaluated RATs, particularly concerning power consumption metrics.

While these findings reinforce the pivotal role of power consumption in guiding RAT selection, it's crucial to acknowledge the potential biases stemming from the decision matrix's real-world data dependency. The inherent favourability towards Wi-Fi in the decision matrix could skew the results, potentially overshadowing the nuanced impact of power consumption variations. Nonetheless, the consistent selection of Wi-Fi underscores the imperative of further exploration into the intricate dynamics of RAT selection, particularly concerning power consumption criteria.

The emphasis on Wi-Fi as the preferred RAT underscores the necessity for a broader investigatory scope. Delving deeper into how different RATs with diverse power consumption criteria respond to varying weight distributions could unveil crucial insights into the complexities of RAT selection. Such analyses offer a pathway to mitigate biases inherent in decision matrices skewed towards specific RATs and real-world performance data. By simulating scenarios wherein each RAT boasts favourable attributes, researchers can unravel the nuanced interplay between weight assignments and RAT selection outcomes across heterogeneous wireless networks.

Chapter 10

Bonus Task: How the Decision Matrix affects RAT Selection

10.1 Scope of the code

In an effort to delve deeper into the multifaceted dynamics of RAT selection within heterogeneous wireless networks, an additional investigation has been initiated. This supplementary analysis aims to explore the impact of a distinct decision matrix on RAT selection outcomes. By introducing a different decision matrix, we seek to illuminate the influence of this critical factor on the RAT selection process. This endeavor not only adds depth to our understanding of RAT selection but also serves to validate the robustness of our simulation framework and results obtained in previous tasks. Through this exploration, we aim to underscore the complexity of RAT selection decisions, which are shaped by a myriad of interplaying factors beyond the weight assignments of individual criteria. This endeavor is poised to provide valuable insights into the intricate dynamics of RAT selection and further enhance our comprehension of wireless network optimisation strategies.

Although the simulation code remains unchanged, the introduction of a new decision matrix marks a significant departure. This adjustment allows for an exploration of how variations in this key parameter affect RAT selection outcomes. By isolating the impact of the decision matrix while maintaining consistency in the simulation framework, this analysis aims to highlight the significance of this factor in shaping RAT selection decisions.

The following decision matrix serves as a pivotal component in our exploration of RAT-selection dynamics within heterogeneous wireless networks. Unlike real-world performance data, these values are crafted to evenly distribute favourable criteria across various RATs, thus providing a controlled environment for assessing the impact of weights on RAT selection. This deliberate manipulation allows us to isolate and scrutinize the influence of weight distributions on selection outcomes, shedding light on the intricate decision-making processes underlying RAT selection.

$$\text{Decision Matrix} = \begin{array}{r} \\ \text{Wi-Fi (W)} \\ \text{2G (G)} \\ \text{4G (L)} \end{array} \begin{array}{c} \begin{array}{ccc} \text{ABW (Mbps)} & \text{D (ms)} & \text{PC (on a scale of 1 to 7)} \end{array} \\ \begin{pmatrix} 500.0 & 50.0 & 2.0 \\ 400.0 & 60.0 & 3.0 \\ 600.0 & 40.0 & 1.0 \end{pmatrix} \end{array}$$

10.2 Simulation Results

In this section, we present the results of our investigation into the effect of varying weights assigned to the allowed bandwidth (ABW), delay (D), and power consumption (PC) criteria on RAT-selection decisions within a wireless network environment. Utilising a meticulously crafted decision matrix designed to have the favourable criteria across Wi-Fi, 2G, and 4G RATs closer in distance, we conducted a series of tests akin to those performed in previous tasks. However, in contrast to previous experiments, this iteration employed a different decision matrix, introducing a new variable into the analysis. Through rigorous simulation and analysis, we aim to shed light on how alterations in weight distribution impact RAT selection outcomes across diverse criteria. The subsequent bar graphs illustrate the deviations in selection outcomes resulting from changes in weight assignments for each criterion, providing valuable insights into the intricate dynamics of RAT selection within real-world network environments.

The first bar graph provides a visual representation of the results obtained from varying the weights assigned to the power consumption (PC) and delay (D) criteria while maintaining a constant value for allowed bandwidth (ABW). In this set of simulations, we use the new decision matrix and compare against the one shown in Figure 7.1. By analysing the trends depicted in the graph, we can gain valuable insights into the impact of weight variations on RAT selection outcomes, providing a deeper understanding of the factors driving network resource allocation and optimisation strategies.

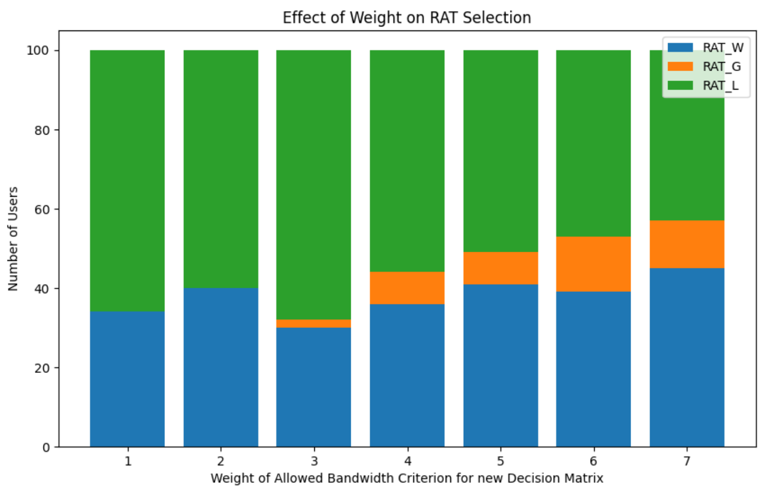

Figure 10.1: Results for Varying Weight Criteria with Constant ABW (New Decision Matrix)

The results depicted in Figure 10.1 reveal interesting patterns regarding RAT selection outcomes under varying weight criteria for allowed bandwidth. Particularly, when the weight assigned to allowed bandwidth is low, we observe a preference for selecting RAT_L, representing 4G networks. This selection can be attributed to the significantly low power consumption (1.0) and relatively low delay (40ms) associated with RAT_L, making it an attractive option under these conditions. As the weight for allowed bandwidth increases, there is a slight increase in the selection of Wi-Fi (RAT_W), indicating its growing prominence. However, it's noteworthy that RAT_G, representing 2G networks, also comes into play with very little effect, despite its lower bandwidth and higher delay compared to Wi-Fi. This nuanced interplay between weight distribution and RAT selection outcomes underscores the complexity of the decision-making process in heterogeneous wireless networks. Furthermore, these findings provide valuable insights into network resource allocation strategies and the impact of random weight assignments on RAT selection dynamics.

The second bar graph, depicted in Figure 10.2, showcases the effect of maintaining a constant value for delay while adjusting the weights assigned to power consumption and allowed bandwidth criteria. Utilising the new decision matrix, this set of simulations provides insights into the influence of varying weight distributions on RAT selection decisions.

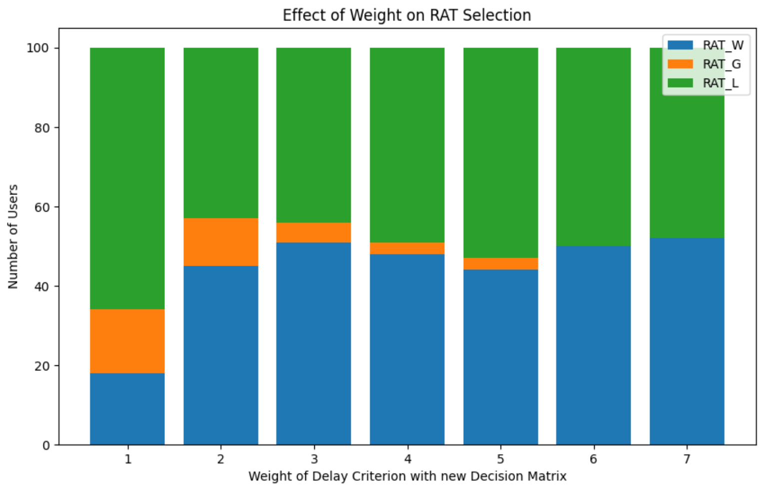

Figure 10.2: Effect of Varying Weights on RAT Selection (Delay Criterion)

From the graph, it is evident that when the weight assigned to the delay criterion is set to 1, there is a notable preference for RAT_L, with relatively similar occurrences of RAT_W and RAT_G. This observation can be attributed to the comparable power consumption and allowed bandwidth of these RATs. However, the selection of RAT_L aligns with its advantageous attributes. As the weight for delay increases, there is a discernible rise in the presence of RAT_W, accompanied by a decrease in RAT_G occurrences. This trend correlates with the delay values associated with each RAT. RAT_W and RAT_L exhibit similar delays, contributing to their increased selection as the weight for delay escalates, whereas RAT_G, characterized by the highest delay, experiences a decline in selection frequency.

The third bar graph below in figure 10.3 illustrates the effect of varying weights on RAT selection outcomes, while maintaining a constant value for power consumption. Like previous analyses, this investigation aims to shed light on how changes in weight distribution impact RAT selection decisions in heterogeneous wireless networks. By examining the relationship between power consumption and other criteria, such as allowed bandwidth and delay, we aim to uncover the factors driving network resource allocation strategies.

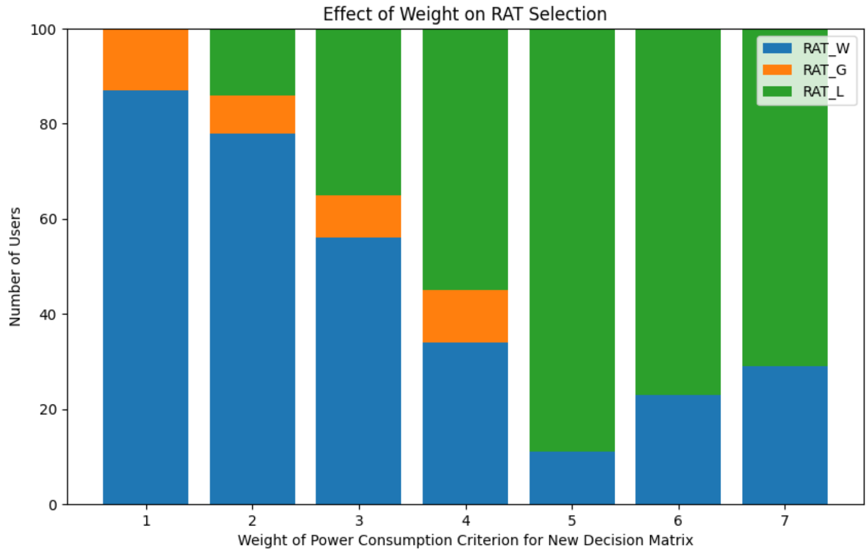

Figure 10.3: Effect of Varying Weight on RAT Selection with Constant Power Consumption

In analyzing the impact of varying weight on RAT selection with a constant power consumption criterion, it's evident that RAT_W exhibits dominance in selection when the weight for power consumption is low. This observation aligns with the characteristics outlined in the decision matrix, where RAT_W boasts a balanced combination of bandwidth and delay. Conversely, while RAT_G shares similar bandwidth characteristics with RAT_W, it possesses higher delay, resulting in its presence in the selection process, albeit to a lesser extent. Interestingly, RAT_L, despite having the highest bandwidth and lowest delay in the decision matrix, initially shows limited presence in selection. However, as the weight for power consumption increases, the prominence of RAT_L becomes more significant. This trend is rationalized by the favourable characteristics of RAT_L, which align with the increasing emphasis on power consumption in the weight assignment.

10.3 Summary of Testing

The prior tasks focused on real-world values, while the aim of this section was to showcase the workings of the simulation script and explore the relationship between weights and RAT selection. Some results could be attributed to the random selection of weights and the attributes of RATs in the decision matrix, but others showed peculiar characteristics, highlighting the complexities of RAT selection and prompting further research. Nevertheless, this section succeeded in demonstrating how the decision matrix affects RAT selection. This relationship, combined with the influence of users' weight preferences, underscores the complexities of this study.

Chapter 11

Task 10: Conclusion

This study investigated the influence of weight assignments on Radio Access Technology (RAT) selection in heterogeneous wireless networks. The initial analyses, which employed a decision matrix reflecting real-world performance data, consistently favoured Wi-Fi (RAT_W) due to its inherent strengths.

However, to isolate the true impact of weight assignments, the final task introduced a modified decision matrix where each RAT possessed favourable attributes in different criteria (bandwidth, delay, and power consumption). This modification revealed nuanced selection patterns based on the weight distribution. For instance, when the weight for allowed bandwidth was low, RAT_L (representing 4G networks) emerged as the preferred choice due to its advantageous power consumption and delay characteristics. Similarly, varying the weights for delay and power consumption demonstrated how RAT selection dynamically adapts based on the emphasized criteria.

These findings highlight the critical role of weight assignments in influencing RAT selection, independent of the specific RAT performance values. This underscores the importance of carefully considering weight assignments within the context of network requirements and user priorities.

While the study acknowledges the limitations of a single modified decision matrix, it paves the way for further investigation. Future research could explore a broader range of decision matrix configurations and incorporate real-world scenarios to validate the findings and develop robust network resource allocation strategies.

In conclusion, this study sheds light on the intricate interplay between weight assignments and RAT selection decisions. By employing a modified decision matrix, the research isolated the true impact of weights, revealing how they significantly influence RAT selection beyond inherent RAT capabilities. This knowledge is instrumental in optimizing network performance and resource allocation in heterogeneous wireless networks.

Bibliography

[1] S. Khera and S. Singh, “A review on research aspects of vertical handover decision based intelligent algorithm,” *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 4, pp. 7207–7213, 08 2015.

[2] J. Santhi and K. Prabha, “Qos aware vertical handover process in heterogeneous wireless network,” *Measurement: Sensors*, vol. 26, pp. 100 710–100 710, 04 2023.

[3] E. Stevens-Navarro and S. Wong, “Comparison between vertical handoff decision algorithms for heterogeneous wireless networks,” *Vehicular Technology Conference*, vol. 2, pp. 947–951, 05 2006.

[4] O. E. Falowo, “Optimal multicriteria rat-selection decisions for multiple handoff calls in heterogeneous wireless networks,” *2016 IEEE 35th International Performance Computing and Communications Conference (IPCCC)*, pp. 1–5, 12 2016.

[5] O. E. Falowo and H. Chan, “Rat selection for multiple calls in heterogeneous wireless networks using modified topsis group decision making technique,” *2011 IEEE 22nd International Symposium on Personal, Indoor and Mobile Radio Communications*, pp. 1371–1375, 09 2011.

[6] O. E. Falowo, “Wireless Networks and Systems Wireless LANs,” Lecture Slides, March 2024, EEE4121F, University of Cape Town.