TOPSIS-based RAT Selection Algorithm for Heterogeneous Wireless Networks

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April 24, 2024

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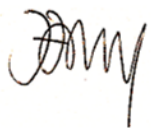

April 24, 2024

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Chapter 1

Task 1: Literature Review

1.1 Introduction

Choosing the right Radio Access Technology (RAT) within Heterogeneous Wireless Networks (HWNs) is a difficult task due to conflicting factors that impair network performance and user experience. This challenge requires RAT selection algorithms that are efficient in taking into account multiple aspects, adapting to dynamic conditions, and meeting user requirements.

Literature review on the multicriteria decision-making MCDM techniques for addressing these challenges includes:

- Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS)
- Multi-Criteria Utility Decision-Making (MCUDM)
- Modified TOPSIS for Group Decision Making in RAT Selection

Additionally, it also briefly compares horizontal and vertical handover mechanisms in HWNs and introduces vertical handover process. This project is aimed at providing a brief overview of RAT selection complexities in HWNs as well as some possible resolutions given by MCDM techniques.

1.2 Comparison of Horizontal and Vertical Handover in HWNs

While both horizontal and vertical handover (HHO and VHO respectively) play crucial roles in maintaining connectivity in HWNs, they address different scenarios and offer distinct advantages and disadvantages. Here's a simplified comparison ([3]):

Horizontal Handover: Switching between base stations using the same RAT (e.g., LTE to LTE). Horizontal handover maintains signal strength and is simpler to implement. However, it has limited performance improvement capabilities and does not address issues such as network congestion or varying service quality offered by different RATs.

Vertical Handover: Switching between base stations using different RATs (e.g., cellular to Wi-Fi). Vertical handover adapts to different network functionalities and service quality, offering the advantage of versatility. However, it may introduce handover delays and require complex algorithms and infrastructure to function effectively.

Choosing between HHO and VHO depends on factors like user needs, network conditions, and available functionalities.

1.2.1 Vertical Handover Process in HWNs

VHO is a critical process in HWNs, facilitating seamless connectivity as devices transition between different networks. Here's an overview of the key steps involved (as discussed in [4]):

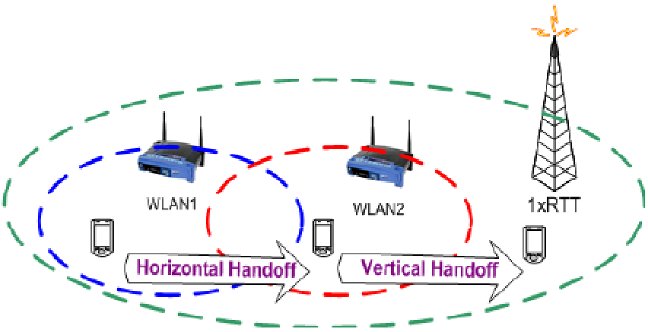

Figure I: Horizontal and Vertical Handoff [1]

1. **Handoff Information Gathering:**
   - Collects information on network parameters (signal strength, bandwidth, etc.) for handover decisions.
2. **Network Selection and Handoff Decision:**
   - Analyzes gathered information to determine when and where to initiate the handover.
   - Employs various algorithms (RSS-based, bandwidth-based, MADM, combination) to make the decision.
3. **Handoff Execution:**
   - Implements the actual transition to the chosen target network.
   - Involves connection establishment, data session transfer, and routing protocol updates.

Control Approaches: NCHO (network-controlled), MAHO (mobile-assisted), and MCHO (mobile-controlled) are different VHO control methods.

Performance Evaluation: Metrics like handoff delay, number of handovers, failure probability, and throughput help determine VHO effectiveness.

1.3 Multicriteria Decision-Making (MCDM) Techniques for RAT Selection

HWNs present a challenge in selecting the optimal RAT due to the presence of multiple, sometimes conflicting, criteria. MCDM techniques offer a structured approach to navigate this complexity, enabling the simultaneous evaluation of various network parameters and user preferences for informed RAT selection decisions.

This section reviews three MCDM techniques applied to RAT selection in HWNs, drawing specific references from the provided papers:

1.3.1 Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS)

TOPSIS, as described by Lahby and Sekkaki, identifies the optimal RAT based on its similarity to positive and negative ideal solutions [2]. These solutions represent the best and worst possible scenarios for all evaluation criteria (e.g., data rate, latency, cost). Each RAT's distance from these ideal solutions is then calculated, and the RAT closest to the positive ideal solution and farthest from the negative ideal solution is considered the most suitable option.

The key aspects of TOPSIS for RAT selection in HWNs, as applied by [2], are as follows:

- **Calculation of RAT Suitability:** TOPSIS calculates the suitability of each RAT by comparing its distance to both the positive ideal solution (best scenario) and negative ideal solution (worst scenario) for evaluation criteria such as signal strength, data rate, and cost.
- **Incorporation of User Preferences through Utility Function:** Lahby and Sekkaki enhanced the TOPSIS approach by incorporating a utility function reflecting user preferences [2]. This allows the system to prioritize RATs aligning with user preferences as well as meeting network performance criteria.
- **Application to VHO Decision-Making:** TOPSIS was applied to VHO scenarios in HWNs, showing its effectiveness in selecting optimal RATs while considering both network parameters and user preferences [2].

The algorithm proposed by Lahby and Sekkaki to improve the performance of vertical handover decisions in heterogeneous networks is shown below in Figure II.

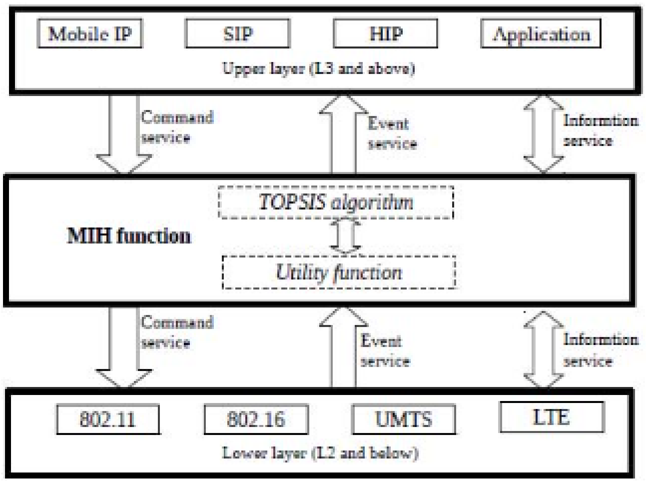

Figure II: The proposed approach for vertical handover based on IEEE 802.21 [2]

The performance and reliability of HWNs are eventually improved by the deployment of TOPSIS for RAT selection in HWNs, which provides an organized and effective method taking user preferences and network performance data into account.

1.3.2 Multi-Criteria Utility Decision-Making

This approach aims to develop a multi-criteria utility decision-making (MCUDM) technique which is designed to take into consideration individual user preferences during RAT selection in HWNs for single or multiple calls [5]. For instance, users engaged in voice calls might prioritize low latency for uninterrupted conversations, while video calls might benefit more from high bandwidth to ensure smooth video streaming.

The MCUDM approach is characterized by the following key aspects:

- **User Preferences Captured through Utility Functions:** User preferences are taken into account as utility functions in this formulation of the RAT selection issue as a Generalized Assignment problem [5]. Because these utility functions are customized for various call kinds, the system can identify and rank the RATs that best achieve user needs.

- **Consideration of Network Resource Constraints:** The MCUDM technique considers user preferences as well as constraints on network resources, such available bandwidth. This guarantees that the selected RAT makes the best use of the resources at hand while also meeting user needs.

- **Strategy for Resource Management:** In situations where there are too few network resources to handle all active calls at once, the MCUDM technique may use selective call dropping. According to [5], this tactic aids in resource allocation management, network stability maintenance, and the avoidance of possible service disruptions.

This approach to RAT selection offers a solution that balances user preferences with network efficiency, which can enhance the overall performance and user experience in HWNs.

1.3.3 Modified TOPSIS for Group Decision Making in RAT Selection

By extending the previously described TOPSIS approach to handle the circumstance of numerous calls with varied priority within a HWN, Falowo and Chan [6] improve upon it. This method acknowledges that various call kinds (voice, video, and data, for example) demand distinct services from the network, and that a single decision rule might not be adequate in all cases.

The authors suggest a modified version of the TOPSIS group decision-making (GDM) method that takes call type-specific user preferences for certain RATs into account. The following are this approach's main features:

- **User preferences are captured through weights:** These weights are assigned to different RAT selection criteria for each call type [6]. These weights reflect the importance of specific criteria like data rate, latency, and power consumption for different calls.

- **Aggregation of individual call weights:** This allows the algorithm to make a collective decision for all ongoing calls. This ensures the chosen RAT satisfies the needs of all calls simultaneously, while considering user priorities.

By considering user preferences, the modified TOPSIS GDM technique offers a dynamic and user-centric approach to RAT selection in HWNs with multiple calls. This approach addresses the limitations of single-criterion decision rules and provides a solution for managing diverse call types and user demands within a HWN.

1.4 Conclusion

Choosing the ideal RAT in HWNs is important but difficult as a result of conflicting considerations. This literature review examined how some MCDM techniques deal with this intricacy. Three of these methods were discussed: TOPSIS, MCUDM, and modified TOPSIS for group decision-making. Each offers a unique approach to address various aspects, user preferences, and resource limitations. MCDM techniques are vital in RAT selection since they allow for optimal network performance as well as improving user experience in HWNs.

Chapter 2

Task 2: System Description and Criteria

2.1 Network Description

2.1.1 Available RATs

The heterogeneous wireless network (HWN) under evaluation consists of the following Radio Access Technologies (RATs):

- **RAT 1: LTE (Long-Term Evolution):** Widely adopted standard for mobile communication, offering high quality coverage and voice call support.
- **RAT 2: Wi-Fi 6:** Latest generation of Wi-Fi technology, known for its high data rates and suitability for video streaming services.
- **RAT 3: 5G NR (New Radio):** Next-generation cellular technology, offering very high data rates and supporting various types of data services.

2.1.2 Supported Calls

Each RAT in the network is designed to excel in supporting a specific class of calls:

- **RAT 1 (LTE):** Voice calls and data services.
- **RAT 2 (Wi-Fi 6):** Data services.
- **RAT 3 (5G NR):** Voice calls and data services.

2.2 Network Criteria

2.2.1 RAT-Selection Criteria

The following three criteria are considered for optimal RAT selection, with each playing a vital role in user experience.

1. **Criterion 1 (Signal Strength):** Measured in dBm, higher values indicate a stronger signal. A strong signal translates to better call quality, fewer dropped calls, and faster data transfer.
2. **Criterion 2 (Data Rate):** Measured in Mbps, higher values represent faster data transfer rates. This criterion becomes crucial for applications requiring high bandwidth, such as video streaming and downloading large files.
3. **Criterion 3 (Delay):** Measured in milliseconds, lower values represent less delay in data transmission. Lower delay is critical for real-time applications such as voice calls and online gaming.

2.2.2 Weights Level for Criteria

Individual users in the network can express their preferences for the criteria using a 7-scale weight system, as detailed in Table I. These weight levels represent the relative importance of each criterion for a particular user. For instance, a user emphasizing low delay for real-time applications may assign a higher weight to *Criterion 3* than a user valuing high data rates for video streaming.

The set of weights is as follows:

Table I: Weights Levels for Criteria

Weight priority	Value
Extremely low	1
Very low	2
Low	3
Medium	4
High	5
Very High	6
Extremely High	7

2.3 Decision Matrix

The decision matrix, denoted as D, plays a central role in the TOPSIS algorithm. Each row of D represents a RAT, and each column represents a criterion. The values in the matrix reflect the performance of each RAT based on the specific criterion. For instance:

$$D = \begin{array}{c|ccc} & \text{Signal Strength (dBm)} & \text{Data Rate (Mbps)} & \text{Delay (ms)} \\ \text{RAT 1 (LTE)} & m_{11} & m_{12} & m_{13} \\ \text{RAT 2 (Wi-Fi 6)} & m_{21} & m_{22} & m_{23} \\ \text{RAT 3 (5G NR)} & m_{31} & m_{32} & m_{33} \end{array}$$

Where m_{ij} is the performance of RAT i on Criterion j.

The following numerical values for the decision matrix have been derived from testing conducted using an iPhone device (gathered via iOS's built-in network data tools and 3rd party data rate measurement tools) connected successively to Wi-Fi, LTE, and 5G networks:

$$D = \begin{array}{c|ccc} & \text{Signal Strength (dBm)} & \text{Data Rate (Mbps)} & \text{Delay (ms)} \\ \text{RAT 1 (LTE)} & -62 & 82.5 & 29 \\ \text{RAT 2 (Wi-Fi 6)} & -58 & 226 & 7 \\ \text{RAT 3 (5G NR)} & -68 & 301 & 28 \end{array}$$

2.3.1 Limitation Note

It is important to acknowledge a notable limitation regarding RAT 2's Data Rate (in Mbps) as presented in the matrix. The recorded Data Rate of 226 Mbps for RAT 2 (Wi-Fi 6) is subject to the imposed limitation set by the Internet Service Provider (ISP) responsible for the connectivity. Specifically, the service plan dictates a maximum of 250 Mbps for both upload and download speeds. Conversely, cellular service providers also have data rate limits, but these are influenced by factors such as the network technology (e.g., 4G LTE, 5G) and network coverage.

Chapter 3

Network Illustration and Flowchart

3.1 Task 3: Heterogeneous Wireless Network Diagram

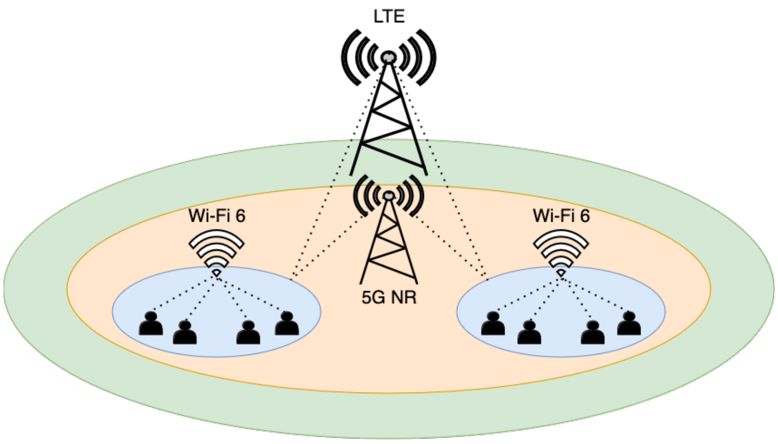

Figure III: Diagram illustrating the heterogeneous wireless network

3.2 Task 4: TOPSIS-based RAT Selection Flowchart

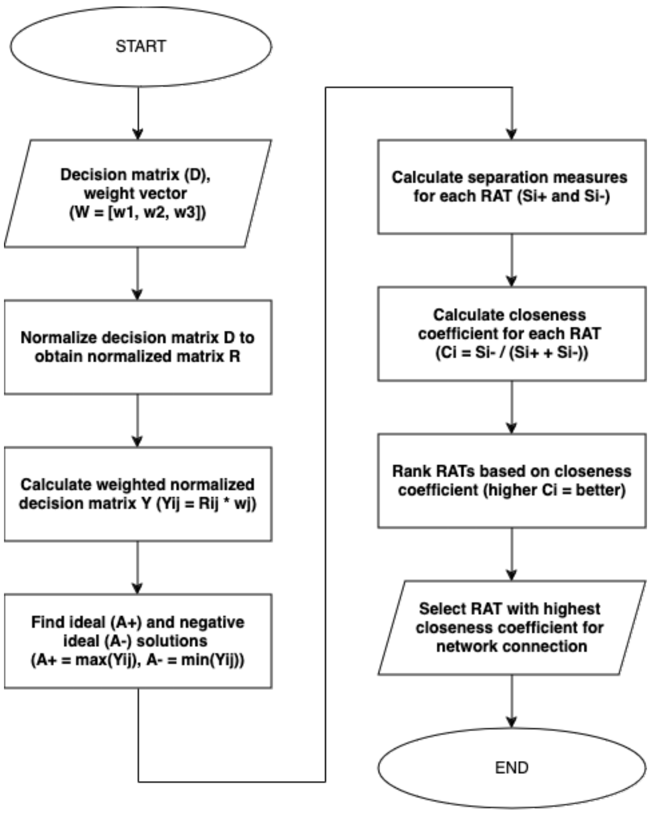

Figure IV: Flowchart illustrating the decision making procedure for RAT-selection in the HWN

Chapter 4

Task 5: TOPSIS Technique - Normalization

4.1 Equation for Normalizing Decision Matrix

To normalize the decision matrix D for TOPSIS analysis, the following equation is used:

For each criterion c_u, where $u = 1, 2, \ldots, X$:

$$\overline{m_{j,u}} = \frac{m_{j,u}}{\sqrt{\sum_{j=1}^{N} m_{j,u}^2}}, \quad j = 1, 2, \ldots, N$$

Where:

- $\overline{m_{j,u}}$ is the normalized performance rating of RAT j on criterion c_u.
- $m_{j,u}$ is the original performance value of RAT j on criterion c_u.
- N is the total number of RATs.
- X is the total number of criteria.

The equation normalizes each performance value $m_{j,u}$ by dividing it by the square root of the sum of the squares of all performance values for the same criterion. This ensures that the normalized values are on a comparable scale, facilitating fair comparison across different criteria.

4.2 Normalized Decision Matrix

The normalized decision matrix R is obtained after applying the normalization equations to each criterion. For the given decision matrix D, the normalized matrix R is as follows:

$$R = \begin{array}{cccc} & \text{Signal Strength} & \text{Data Rate} & \text{Delay (ms)} \\ \text{RAT 1 (LTE)} & \overline{m_{11}} & \overline{m_{12}} & \overline{m_{13}} \\ \text{RAT 2 (Wi-Fi 6)} & \overline{m_{21}} & \overline{m_{22}} & \overline{m_{23}} \\ \text{RAT 3 (5G NR)} & \overline{m_{31}} & \overline{m_{32}} & \overline{m_{33}} \end{array}$$

Substituting the given values for D in section 2.3:

$$R = \begin{array}{cccc} & \text{Signal Strength} & \text{Data Rate} & \text{Delay (ms)} \\ \text{RAT 1 (LTE)} & \frac{-62}{\sqrt{(-62)^2+(-58)^2+(-68)^2}} & \frac{82.5}{\sqrt{82.5^2+226^2+301^2}} & \frac{29}{\sqrt{29^2+7^2+28^2}} \\ \text{RAT 2 (Wi-Fi 6)} & \frac{-58}{\sqrt{(-62)^2+(-58)^2+(-68)^2}} & \frac{226}{\sqrt{82.5^2+226^2+301^2}} & \frac{7}{\sqrt{29^2+7^2+28^2}} \\ \text{RAT 3 (5G NR)} & \frac{-68}{\sqrt{(-62)^2+(-58)^2+(-68)^2}} & \frac{301}{\sqrt{82.5^2+226^2+301^2}} & \frac{28}{\sqrt{29^2+7^2+28^2}} \end{array}$$

$$\Rightarrow R = \begin{array}{cccc} & \text{Signal Strength} & \text{Data Rate} & \text{Delay (ms)} \\ \text{RAT 1 (LTE)} & -0.569 & 0.214 & 0.709 \\ \text{RAT 2 (Wi-Fi 6)} & -0.533 & 0.587 & 0.171 \\ \text{RAT 3 (5G NR)} & -0.625 & 0.781 & 0.684 \end{array}$$

After calculating the normalized values, the resulting normalized decision matrix R can be used for further steps in the TOPSIS algorithm.

Chapter 5

Task 6: Ranking RATs using TOPSIS

After obtaining the normalized decision matrix R, the following steps are performed to rank the available RATs for a new or vertical handoff call in the heterogeneous wireless network:

5.1 Step 1: Calculate the Normalized Weight

The normalized weight W is calculated using the weights assigned to each criterion by the user:

$$W_u = \frac{w_u}{\sqrt{\sum_{i=1}^{X} w_i^2}}$$

Where $u = 1, 2, \ldots, X$, and X is the number of criteria.

5.2 Step 2: Calculate the Weighted Normalized Decision Matrix

The weighted normalized decision matrix V is obtained by multiplying each normalized decision matrix element $\overline{m_{j,u}}$ by the corresponding normalized weight W_u:

$$V_{j,u} = \overline{m_{j,u}} \times W_u, \quad j = 1, 2, \ldots, N \quad \text{and} \quad u = 1, 2, \ldots, X$$

5.3 Step 3: Determine the Ideal Solution and Negative Ideal Solution

The ideal solution (A^*) representing the best performance for each criterion is calculated as follows:

$$A^* = [h_1^*, h_2^*, \ldots, h^*]$$

$$h_u^* = \begin{cases} \max(V_{1,u}, V_{2,u}, V_{3,u}) & \text{if } c_u \in C' \\ \min(V_{1,u}, V_{2,u}, V_{3,u}) & \text{if } c_u \in C'' \end{cases}$$

Similarly, the negative ideal solution (A^-) representing the worst performance for each criterion is calculated as:

$$A^- = [h_1^-, h_2^-, \ldots, h^-]$$

$$h_u^- = \begin{cases} \min(V_{1,u}, V_{2,u}, V_{3,u}) & \text{if } c_u \in C' \\ \max(V_{1,u}, V_{2,u}, V_{3,u}) & \text{if } c_u \in C'' \end{cases}$$

where c_u is the criterion u, C' is the set of benefit criteria, and C'' is the set of negative criteria. Note that $C = C' + C''$.

5.4 Step 4: Calculate the Closeness Coefficient

The closeness coefficient CC_j for each RAT j is calculated using the Euclidean distance from the ideal solution (A*) and the negative ideal solution (A-):

$$d_j^* = \sqrt{\sum_{u=1}^{N}(V_{j,u} - A_u^*)^2}, \quad j = 1, 2, ..., N$$

$$d_j^- = \sqrt{\sum_{u=1}^{N}(V_{j,u} - A_u^-)^2}, \quad j = 1, 2, ..., N$$

$$CC_j = \frac{d_j^-}{d_j^* + d_j^-}, \quad \forall \quad j = 1, 2, ..., N$$

5.5 Worked Ranking Example

Using the normalized decision matrix R from section 4.2 and weights $w_1 = 4$, $w_2 = 3$, and $w_3 = 3$ as the inputs, the process described in the sections above can be worked through.

The normalized weight is then calculated:

$$W = \begin{pmatrix} w_1 & w_2 & w_3 \\ 4 & 3 & 3 \end{pmatrix}$$

$$W_u = \frac{w_u}{\sqrt{4^2 + 3^2 + 3^2}}$$

$$\Rightarrow W = \begin{pmatrix} w_1 & w_2 & w_3 \\ 0.686 & 0.514 & 0.514 \end{pmatrix}$$

The weighted normalized decision matrix can then be calculated:

$$V = \begin{array}{cccc} & \text{Signal Strength} & \text{Data Rate} & \text{Cost} \\ \text{RAT 1 (LTE)} & -0.569 \times 0.686 & 0.214 \times 0.514 & 0.709 \times 0.514 \\ \text{RAT 2 (Wi-Fi 6)} & -0.533 \times 0.686 & 0.587 \times 0.514 & 0.171 \times 0.514 \\ \text{RAT 3 (5G NR)} & -0.625 \times 0.686 & 0.781 \times 0.514 & 0.684 \times 0.514 \end{array}$$

$$\Rightarrow V = \begin{array}{cccc} & \text{Signal Strength} & \text{Data Rate} & \text{Cost} \\ \text{RAT 1 (LTE)} & -0.391 & 0.110 & 0.365 \\ \text{RAT 2 (Wi-Fi 6)} & -0.366 & 0.302 & 0.088 \\ \text{RAT 3 (5G NR)} & -0.429 & 0.402 & 0.352 \end{array}$$

The ideal and negative ideal solutions for each criterion are then calculated (*Note: Signal Strength and Data Rate are benefit criteria*):

Ideal Solution (A^*):

$$A^* = \begin{pmatrix} \text{Signal Strength} & \text{Data Rate} & \text{Delay (ms)} \\ \max(V_{1,1}, V_{2,1}, V_{3,1}) & \max(V_{1,2}, V_{2,2}, V_{3,2}) & \min(V_{1,3}, V_{2,3}, V_{3,3}) \end{pmatrix}$$

$$\Rightarrow A^* = \begin{pmatrix} \text{Signal Strength} & \text{Data Rate} & \text{Delay (ms)} \\ -0.366 & 0.402 & 0.088 \end{pmatrix}$$

Negative Ideal Solution (A^-):

$$A^- = \begin{pmatrix} \text{Signal Strength} & \text{Data Rate} & \text{Delay (ms)} \\ \min(V_{1,1}, V_{2,1}, V_{3,1}) & \min(V_{1,2}, V_{2,2}, V_{3,2}) & \max(V_{1,3}, V_{2,3}, V_{3,3}) \end{pmatrix}$$

$$\Rightarrow A^- = \begin{pmatrix} \text{Signal Strength} & \text{Data Rate} & \text{Delay (ms)} \\ -0.429 & 0.110 & 0.365 \end{pmatrix}$$

The separation measures for all RATs are then calculated:

$$d_1^* = \sqrt{(-0.391 - -0.366)^2 + (0.110 - 0.402)^2 + (0.365 - 0.088)^2} = 0.403$$

$$d_2^* = \sqrt{(-0.366 - -0.366)^2 + (0.302 - 0.402)^2 + (0.088 - 0.088)^2} = 0.100$$

$$d_3^* = \sqrt{(-0.429 - -0.366)^2 + (0.402 - 0.402)^2 + (0.352 - 0.088)^2} = 0.271$$

$$d_1^- = \sqrt{(-0.391 - -0.429)^2 + (0.110 - 0.110)^2 + (0.365 - 0.365)^2} = 0.038$$

$$d_2^- = \sqrt{(-0.366 - -0.429)^2 + (0.302 - 0.110)^2 + (0.088 - 0.365)^2} = 0.342$$

$$d_3^- = \sqrt{(-0.429 - -0.429)^2 + (0.402 - 0.110)^2 + (0.352 - 0.365)^2} = 0.292$$

The closeness coefficient matrix is then calculated:

$$CC = \begin{pmatrix} & \text{Closeness Coefficient} \\ \text{RAT 1 (LTE)} & \frac{0.038}{0.403+0.038} \\ \text{RAT 2 (Wi-Fi 6)} & \frac{0.342}{0.100+0.342} \\ \text{RAT 3 (5G NR)} & \frac{0.292}{0.271+0.292} \end{pmatrix}$$

Therefore, the closeness coefficient matrix is calculated as:

$$CC = \begin{pmatrix} & \text{Closeness Coefficient} \\ \text{RAT 1 (LTE)} & 0.086 \\ \text{RAT 2 (Wi-Fi 6)} & 0.774 \\ \text{RAT 3 (5G NR)} & 0.518 \end{pmatrix}$$

After calculating the CC values for each RAT, the RAT with the highest closeness coefficient represents the best choice for the new or vertical handoff call in the heterogeneous wireless network. In this example the best choice is RAT 2 (Wi-Fi 6).

Chapter 6

Effect of Weight on RAT Selection

The effect of users' weights assigned to each RAT-selection criterion on the decisions for new or vertical handoff calls in the HWN is evaluated in this chapter. The three criteria considered are Signal Strength, Data Rate, and Delay. The weights assigned to these criteria are varied to observe how they influence the ranking of RATs.

6.1 Methodology

The evaluation of users' weights on RAT selection decisions in the heterogeneous wireless network (HWN) was conducted through a systematic approach. The following steps outline the testing methodology based on chapter 5.

6.1.1 Steps of Methodology

1. **Data Preparation and Normalization**

   - **Decision Matrix:** The decision matrix D, representing RAT performance across the criteria of Signal Strength, Data Rate, and Delay, was derived from empirical testing, as shown in section 2.3.

   - **Normalization:** This matrix was then normalized to create matrix R, ensuring that performance values were on a comparable scale for fair cross-criteria comparison.

2. **Weighted Matrix Calculation**

   - **Fixed Criterion Weight Testing:** The weight of one specific criterion (e.g., Signal Strength) was held constant at each of its possible levels (1 to 7) through multiple iterations. For each fixed level, the RAT selection process was repeated 1000 times.

   - **Random Weight Assignment for Other Criteria:** While the weight for one criterion was fixed, weights for the other criteria were randomly assigned values between 1 (Extremely Low) and 7 (Extremely High) during each of the 1000 iterations.

3. **Ideal and Negative Ideal Solutions**

   - **Computation of Solutions:** From the weighted normalized matrices calculated in the previous step, the ideal and negative ideal solutions were determined. These solutions indicate the best and worst possible performance scenarios for each criterion, guiding the RAT selection process.

4. **Closeness Coefficient Calculation**

   - **Determination of Proximity:** Closeness coefficients were computed to quantify how closely each RAT approaches the ideal solution. This measure is crucial for ranking the

RATs and is recalculated in each of the 1000 iterations for each weight level of the fixed criterion.

5. **Visualization**

   - **Representation of Results:** Bar charts were utilized to visualize the effects of varying weights on RAT selection decisions. These charts display the frequency of each RAT being chosen, illustrating the impact of different weight levels across a range of user-defined preferences.

6.1.2 Execution of Tests

Each test sequence involved systematically varying the weight for one of the criteria across its full range while assessing the impact on RAT selection. This process was executed separately for each criterion, with each weight level tested over 1000 iterations, totaling 7000 iterations per criterion to thoroughly explore the influence of each weight setting.

6.2 Task 7: Evaluating the Impact of Signal Strength on RAT Selection

Signal strength plays an important role in ensuring reliable communication and high-quality service in heterogeneous wireless networks. This section investigates the effects of assigning varying weights to the signal strength criterion on RAT selection decisions.

6.2.1 Results

Distribution of RAT Selections

Figure V displays the impact of varying signal strength weights on RAT selections. This data was collected through a series of trials where the weight for the signal strength criterion was fixed, and weights for other criteria were randomly assigned.

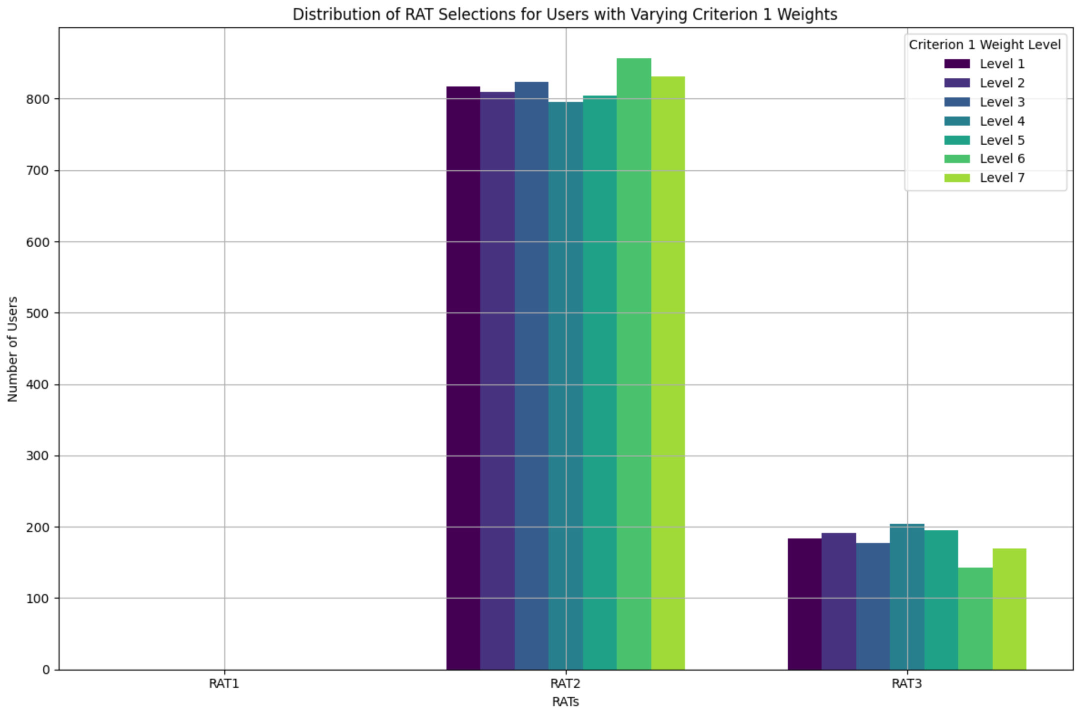

Figure V: Distribution of RAT Selections for Users with Varying Signal Strength Criterion Weights

Average Weights Leading to RAT Selections

Figure VI shows the average weight levels assigned to all criteria that influenced users' RAT selections. This chart offers insights into the effect of signal strength weights on selection preferences.

Figure VI: Average Weight Levels for each Selected RAT for Signal Strength Trials

Data Overview

Table II provides the raw data from the RAT selection trials, detailing the number of users who selected each RAT at varying signal strength weight levels.

Weight Level	RAT1	RAT2	RAT3
1	0	817	183
2	0	809	191
3	0	823	177
4	0	796	204
5	0	805	195
6	0	857	143
7	0	831	169
Average	0	819.7	180.3

Table II: Number of Users Selecting Each RAT for Different Weight Levels for Signal Strength Trials

6.2.2 Analysis of Results

The data illustrated in Figure V consistently shows that RAT2 (Wi-Fi 6) is the predominant choice across all weight levels, largely due to its favorable balance of signal strength, data rate, and low delay. Despite offering higher data rates, RAT3 (5G NR) is selected by a smaller percentage of users, indicating a preference that varies with the desired balance of criteria, as further evidenced in Figure VI.

Notably, no users selected RAT1 (LTE), suggesting that its performance characteristics are not competitive when compared to RAT2 and RAT3 under the studied conditions. The preference for RAT2 in 82% of cases indicates a strong user inclination towards this RAT under typical signal strength considerations, while the remaining 18% of users opting for RAT3 highlight a niche preference possibly driven by higher data rate requirements.

This analysis suggests that even if a RAT has lower signal strength, the TOPSIS algorithm might recommend it based on a more favorable overall balance of criteria, confirming the algorithm's efficacy in making holistic network selection decisions.

6.3 Task 8: Evaluating the Impact of Data Rate on RAT Selection

Data rate is an important criterion influencing user experience in a heterogeneous wireless network. This section examines how varying the importance of the data rate criterion affects RAT selection decisions.

6.3.1 Results

Distribution of RAT Selections

The distribution of RAT selections with varying data rate weights is shown in Figure VII. The experiment was designed to hold the data rate weight constant across a series of trials while randomly varying the weights for the other criteria.

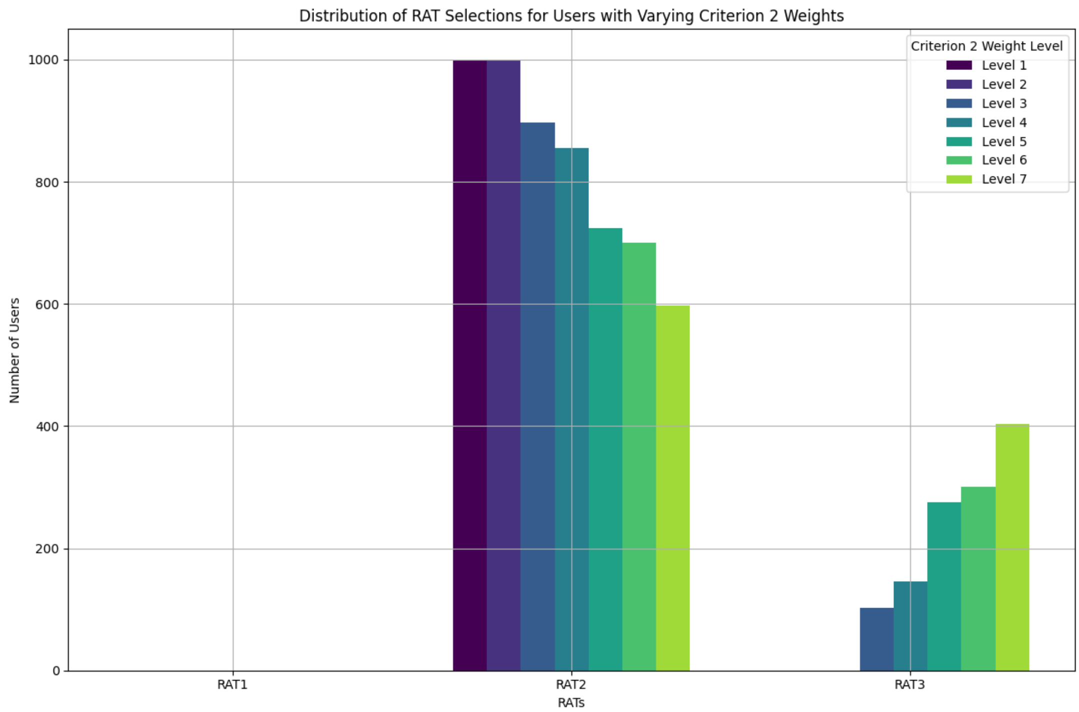

Figure VII: Distribution of RAT Selections for Users with Varying Data Rate Criterion Weights

Average Weights Leading to RAT Selections

Figure VIII shows the average weight levels assigned to all criteria that influenced users' RAT selections. This chart offers insights into the effect of data rate weights on selection preferences.

Figure VIII: Average Weight Levels for each Selected RAT for Data Rate Trials

Data Overview

Table III provides the raw data from the RAT selection trials, detailing the number of users who selected each RAT at varying data rate weight levels.

Weight Level	RAT1	RAT2	RAT3
1	0	1000	0
2	0	1000	0
3	0	897	103
4	0	855	145
5	0	724	276
6	0	700	300
7	0	597	403
Average	0	824.7	175.3

Table III: Number of Users Selecting Each RAT for Different Weight Levels for Data Rate Trials

6.3.2 Analysis of Results

The data presented in Figure VII and Table III show a clear trend: as the weight assigned to the data rate criterion increases, the number of users choosing RAT2 decreases, while those selecting RAT3 increases. This shift suggests that users prioritize higher data rates as the weight increases, moving away from RAT2, which, despite its lower delay, offers a less competitive data rate compared to RAT3.

Figure VIII further confirms this behavior, showing that the average weight leading to the selection of

RAT3 increases notably for data rate, indicating a preference for higher data rates. In contrast, RAT2 is consistently selected when lower weights are assigned to the data rate, reflecting its adequacy for users with less demanding data rate needs.

The complete absence of selections for RAT1 across all trials suggests that its performance characteristics in terms of data rate and other criteria are insufficient to make it a competitive choice under the tested conditions.

6.4 Task 9: Evaluating the Impact of Delay on RAT Selection

This section explores the influence of varying the weight assigned to the delay criterion on RAT selection decisions. Delay, a critical factor affecting real-time communications, can significantly influence user preferences for network selection.

6.4.1 Results

Distribution of RAT Selections

The distribution of RAT selections with varying delay weights is shown in Figure IX. The experiment was designed to hold the delay weight constant across a series of trials while randomly varying the weights for the other criteria.

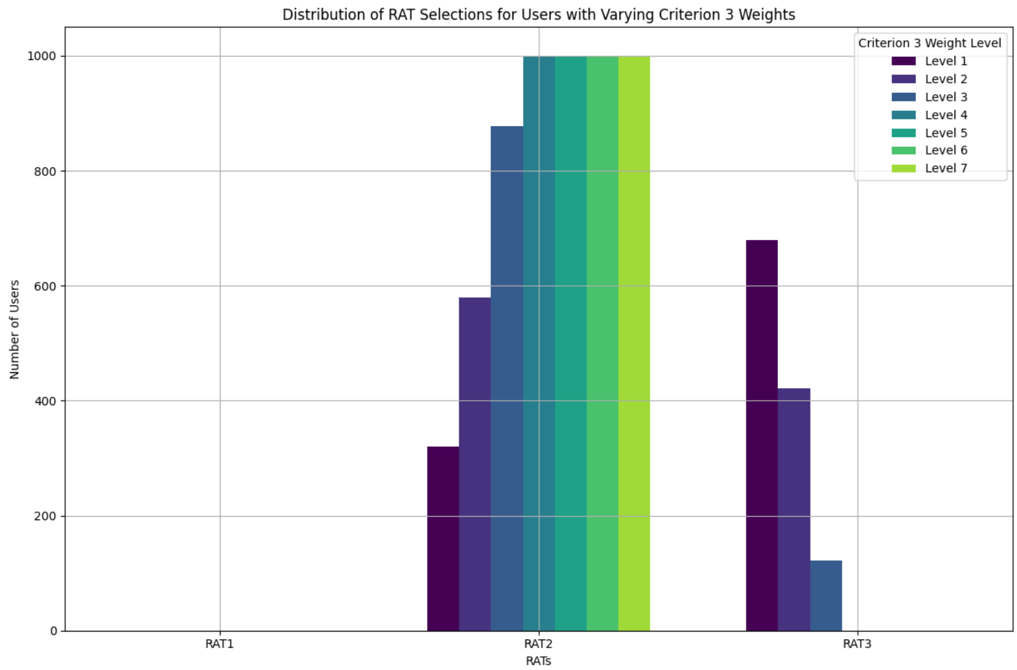

Figure IX: Distribution of RAT Selections for Users with Varying Delay Criterion Weights

Average Weights Leading to RAT Selections

Figure X shows the average weight levels assigned to all criteria that influenced users' RAT selections. This chart offers insights into the effect of delay weights on selection preferences.

Figure X: Average Weight Levels for each Selected RAT for Delay Trials

Data Overview

Table IV provides the raw data from the RAT selection trials, detailing the number of users who selected each RAT at varying delay weight levels.

Weight Level	RAT1	RAT2	RAT3
1	0	320	680
2	0	579	421
3	0	878	122
4	0	1000	0
5	0	1000	0
6	0	1000	0
7	0	1000	0
Average	0	825.3	174.7

Table IV: Number of Users Selecting Each RAT for Different Weight Levels for Delay Trials

6.4.2 Analysis of Results

As depicted in Figure IX, RAT2 (Wi-Fi 6) becomes increasingly favored as the weight on delay criterion increases, particularly from levels 2 through 7, due to its superior performance in minimizing delay. Interestingly, at the lowest weight level (1), RAT3 (5G NR) is preferred by a majority, possibly reflecting its competitive data rates and satisfactory signal strength, outweighing its slightly higher delay compared to RAT2.

The absence of any selections for RAT1 (LTE) across all weight levels suggests its performance in terms of delay, and other criteria do not meet user expectations under any delay weighting scenario. This consistent choice of RAT2 in about 82.5% of cases, with the remainder selecting RAT3, illustrates a clear user preference trend influenced by the delay criterion, affirming the TOPSIS algorithm's effectiveness in aligning RAT selections with user-defined weights.

6.5 Discussion

The analysis of user-assigned weights to the criteria of Signal Strength, Data Rate, and Delay in a heterogeneous wireless network (HWN) demonstrates the effectiveness of the TOPSIS multi-criteria decision-making method. The absence of selections for RAT1 (LTE) across all tests suggests its limited appeal compared to newer technologies like Wi-Fi 6 and 5G NR, highlighting the need for continuous evaluation and potential upgrade of network technologies to meet evolving user expectations and technological advancements.

The shifts in user preferences with changing weights—favoring Wi-Fi 6 for its low delay and 5G NR for its high data rates—underline the distinct advantages each RAT offers for specific applications. This indicates that user-centric network selection, which aligns network performance with individual user needs, is not only feasible but also enhances user satisfaction and optimizes network resource utilization.

Chapter 7

Task 10: Conclusion

In this project, the impact of varying weights assigned to Signal Strength, Data Rate, and Delay criteria on the selection of Radio Access Technologies (RATs) in a Heterogeneous Wireless Network (HWN) was explored. The evaluation was conducted using the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) algorithm, which provides a systematic and efficient approach to RAT selection considering multiple criteria.

The findings of our analysis reveal significant insights into the decision-making process for RAT selection, emphasizing the crucial role of user-defined weights in determining the most suitable RAT for new or vertical handoff calls. Key observations from our investigation are summarized below:

Signal Strength Criterion

- The analysis demonstrated a consistent preference for RAT2 (Wi-Fi 6) across all weight levels when signal strength was prioritized, underscoring its robust coverage and reliability within the HWN.
- RAT3 (5G NR), despite its lower signal strength relative to RAT2, was preferred over RAT1 (LTE), highlighting the algorithm's capability to evaluate the overall service quality beyond a single criterion.

Data Rate Criterion

- As the importance of data rate increased, users shifted their preference towards RAT3 (5G NR) for its superior data handling capabilities, crucial for high-bandwidth applications.
- However, RAT2 (Wi-Fi 6) remained the most popular choice at across all weight levels, reflecting its balanced performance across multiple criteria, including low delay and adequate data rates.

Delay Criterion

- RAT2 (Wi-Fi 6) was increasingly favored as weights on the delay criterion escalated from levels 2 to 7, demonstrating its superior capability in scenarios requiring low latency.
- At the lowest weight level (1), RAT3 (5G NR) emerged as the preferred choice, indicating that its advantage in data rate was significant enough to offset its relatively higher delay compared to RAT2.

This project emphasizes the significance of user-defined weights in shaping RAT selection decision in HWNs. The TOPSIS algorithm offers a structured and efficient method for network operators to optimize RAT selection based on diverse user preferences and network conditions. By understanding the impact of criteria weights, network administrators can tailor RAT selection strategies to meet specific user needs, improve network performance, and enhance the overall user experience.

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