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Heterogeneous Wireless Network Selection based on MADM with Ensemble Average Method

A Thesis

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بسم الله الرحمن الرحيم

{يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ}

[المجادلة: ١١]

صدق الله العلي العظيم

Supervisor Certification

I certify that the thesis entitled (**Heterogeneous Wireless Network Selection based on MADM with Ensemble Average Method**) is prepared under my supervision at the department of Information Networks/ College of Information Technology/University of Babylon as partial fulfillment of the requirements of the degree of Master in Information Technology-Information Networks.

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In view of the available recommendations, I forward the thesis entitled "**Heterogeneous Wireless Network Selection based on MADM with Ensemble Average Method**" for debate by the examination committee.

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Dedication

To the two purest hearts in my life... my dear parents.

My faithful husband who shared good and bad times with me, and never tired of encouraging me…

To my brother and sister My only supporter.

To whom I look forward to seeing their bright future, God willing....... My dear children.

all my family, everyone who supported me with a word and stance, and all my friends.

Acknowledgement

In the name of God, Most Gracious, Most Merciful

First and foremost, I thank God Almighty for His innumerable blessings ... My God, to you, be praise and thanks giving until praise reaches its limit ... And your praise and grace have no bounds. Praise Allah for always helping me to achieve my aims.

My great thanks and gratitude to all in the College of Information Technology at the University of Babylon, and especially in particular, Thanks and gratitude go to (Dr. Rasim Azeez Kadhim) honorable supervisor for his support in completing this work.

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Fatima Sameer Hassan

Abstract

In the next generation heterogeneous wireless and mobile networks, the mobile terminal equipped with a multi-interface may be able to choose an optimal access network anywhere and at any time. The seamless handover between different technologies is referred to as vertical handover (VHO). However, the main challenge is to provide seamless connectivity to the mobile terminal in this heterogeneous environment. Therefore, VHO needs an effective network selection process based on multiple network parameters. This thesis presents a new network selection algorithm based on MADM techniques represented by the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Grey relational analysis (GRA), VIseKriterijumska Optimizacija I Kompromisno Resenje, (VIKOR) with the ensemble average to rank alternative networks.

Many metrics are used to evaluate the system represented by the handover, network delay, network jitter, packet loss rate, throughput and the cost. The proposed method is implemented and simulated in two scenarios: the first scenario considered a constant location of the node with randomly 100 trails and repeated for 100 times. While the second scenario adopted a moving node according to a specific path with 350 steps and selection trails. The simulation results of all scenarios showed that the proposed method obtained a lowest value of average vertical handover in comparison to TOPSIS, GRA and VIKOR. Also, the network delay and jitter were reduced about less than 25% compared to GRA and VIKOR for two scenarios. In addition to that the proposed method increased the throughput about 2% and reduced the packet loss rate about 10%. While the cost was increased in the first scenario and the second scenario showed the same cost for all methods. Finally, the proposed method provided a good performance in terms of the network metrics and the reliability but the complexity of the system was increased.

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List of Abbreviations

Abbreviation	Description
AMPS	Advanced Mobile Phone System
CDMA	Code Division Multiple Access,
CV	Coefficient of Variation
DoCoMo	do communications over the mobile network
DSL	Digital Subscriber Line
ETSI	Telecommunications Standards Institute
EW	entropy weighted
FAHP	fuzzy analytic hierarchy process
FANP	Fuzzy Analytic Network Process
GRA	Grey Relational Analysis
GRC	grey relational coefficient
GSM	Global System for Mobile Communications
HWN	heterogeneous wireless network
LTE	Long-Term Evolution
MADM	multiple attribute decision-making
MEW	multiplicative exponent weighting
MAHO	Mobile-Assisted Handover
NAHO	Network-Assisted Handover
NTT	Nippon Telegraph and Telephone
PSO	particle swarm optimization-
QoS	Quality of services
RATs	Radio access technologies
SAW	Simple additive weighting method
SD	Standard deviation

TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UMTS	Universal Mobile Telecommunication Service
VIKOR	VlseKriterijumska Optimizacija Kompromisno Resenje Multi-Criteria Optimization and Compromise Solution
VHO	Vertical handover
WLAN	Wireless Local Area Network
WIMAX	Worldwide Interoperability for Microwave Access
Wi-Fi	Wireless-Fidelity
WCDMA	Wideband Code Division Multiple Access

Chapter One

Introduction

1.1 Overview

The evolution of wireless networks has a history dating back to the end of the 19th century when Guglielmo Marconi demonstrated the initial practical implementation of wireless communication by transmitting radio signals across the Atlantic Ocean. This breakthrough led to the development of wireless telegraph systems, which are widely used for long-distance communication during World War I and beyond [1], [2].

In the 1940s and 1950s, the first wireless networks for mobile communication are developed for use by the military and other specialized applications. These networks are based on analog radio signals and are limited in their coverage and capacity.

In the 1980s and 1990s, digital wireless networks began to emerge, with the introduction of cellular networks based on the Advanced Mobile Phone System (AMPS) and later the Global System for Mobile Communications (GSM) standard. These networks allowed for the development of new services like text messaging and mobile data while also allowing for more effective use of the radio spectrum [3], [4].

The development of Wi-Fi technology in the late 1990s and early 2000s revolutionized wireless networking by enabling wireless internet access for computers and other devices. To transmit data over short distances, Wi-Fi networks rely on radio waves, typically within a few hundred feet, and are widely used in homes, offices, and public spaces.

In the 2010s and beyond, wireless networks have continued to evolve with the introduction of new standards such as 4G LTE and 5G, which provide higher speeds, lower latency, and greater capacity for mobile data communication. These networks have enabled the development of new services and applications, such as cloud computing and streaming video, that rely on fast and reliable wireless connectivity [5].

1.2 Problem Statement

Heterogeneous Wireless Networks (HWNs) encompass a diverse range of wireless technologies, including Wi-Fi, cellular networks (3G, 4G, and 5G), Bluetooth, and more. Users and devices are surrounded by multiple available networks, each with distinct characteristics such as data rates, latency, coverage areas, energy consumption, and costs. The challenge at hand is to develop an intelligent network selection algorithm that optimizes connectivity in HWNs, ensuring seamless user experience, efficient resource utilization, and adaptable decision-making.[1],[4],[6].

1.3 Aims of the thesis

The aim of this thesis is to address the following critical challenges in designing a network selection algorithm for HWNs and this aim done by following objectives:

1- Developing a network selection method based on multiple techniques and the ensemble average method for selecting the radio access network that a Mobile Node will use to acquire the best services.

2- To implement the MADM techniques.

3- To validate the developed method by the simulation.

4- Comparing the results of the developed method with some of the most closely relevant works in terms of the metrics of the network performance.

1.4 Related works

In 2014, Zhang et al. enhanced the multiple attribute decision-making (MADM) using a new algorithm based on group decision theory. The approach created a combinational weight vector by combining weight vectors from several attribute decision-making. The compatibility of the findings will next be evaluated. If they don't accomplish the compatibility standards, the judgment matrix will be tweaked until a complete vector meets the compatibility requirements. For network selection, the vector is combined with the simple weighting method (SW). Simulations suggest that the algorithm can deliver a decent QoS to users [1].

In 2016, Liangrui Tang et al. devised an approach to transform the problem of network access selection into a multi-attribute decision-making problem that considers attribute interdependencies. The network selection scheme based on VlseKriterijumska Optimizacija Kompromisno Resenje (VIKOR) method, one of MADM methods. This technique was implemented and simulated with Network Simulator NS-3. Also, this technique is validated and compared with other MADM methods as baseline schemes [2].

In 2016, He-Wei Yu and Biao Zhang proposed a novel method for selecting the most suitable network in a heterogeneous network environment is proposed. This method combines fuzzy analytic hierarchy process (FAHP), standard deviation, and grey relational analysis (GRA) to consider utility value and attribute weight. By calculating a comprehensive assessment value for each candidate network, this technique determines the network that meets or exceeds a predefined threshold. If a suitable network is found, the handover procedure begins; otherwise, the terminal remains connected to the current network. Simulation results demonstrate that this approach outperforms four existing baseline algorithms by quickly identifying the best network for different traffic classes, reducing the frequency of vertical handovers and minimizing ping-pong effect [3].

In 2018, Gen Liang and Hewei Yu presented a technique where objective weight and subjective weight are calculated using the entropy method and FAHP respectively. FAHP is specifically used to determine the user preference values of services for candidate networks.

Next, the algorithm employs various techniques, including multiplicative exponent weighting (MEW), simple additive weighting (SAW), and technique for order preference by similarity to an ideal solution (TOPSIS), to compute a score for each candidate network. These scores are determined based on the assigned utility values and weights for network attributes. To accommodate user preferences, the algorithm converts these evaluations into a comprehensive score for each candidate network [4].

In 2020, Radouche, S. and Leghris, C, proposed a novel approach for network selection process using the cosine similarity that rank alternative networks. Additionally, incorporate both subjective weights and objective weights determine using the EM, to enhance selection process. It uses number of handover and rank abnormal as performance metrics [5].

In 2020, Hewei Yu et al. developed a selection algorithm by combining the Intuitionistic Normal FAHP and Improved GRA. This algorithm is MADM techniques that considers both SW and OW. It used semantic relevance of intuitionistic normal fuzzy numbers and applies INFAHP to determine the SW of network properties. Additionally, the objective weight is calculated using the Coefficient of Variation (CV) and then combined to obtain the final weights. Subsequently, IGRA rank candidate networks based on these weights [6].

In 2021, Said Radouche and Cherkaoui Leghris introduced a novel approach for network selection within access networks. The proposed technique integrates cosine similarity distance, subjective weights acquired through Fuzzy Analytic Network Process (FANP), and objective weights obtained via particle swarm optimization. By computing the cosine similarity distance between each network and the ideal network, the approach derives comprehensive weights. In the vertical handover (VHO) network selection phase, the network exhibiting the shortest cosine distance to the ideal network is chosen. In comparison to existing MADM methods, the integration of cosine similarity distance and combination weights in this approach effectively mitigates ranking abnormalities and reduces the handover [7].

Table 1.1: Summary of the related works.

Reference	Year	Proposed model	Method used	networks	parameters
[1]	2014	An improved network selection algorithm is presented by combining several weight vectors of (MADM) using group decision theory. standard deviation and entropy weighted method are all presented.	objective weighted vector is calculated using the EW and SD method.	Base stations for (WLAN), two (WiMAX) stations, and two (UMTS) stations	The peak data rate, packet loss, packet jitter, cost per bit, packet delay, and bandwidth
[2]	2016	Proposed automatic and real-time selection of the next handed network in heterogeneous environment consisting of networks, while maintaining the best QoS. based on VIKOR method which consider multiple attributes for the decision of the best available alternatives. The simulation experiment presented with Network Simulator NS-3	VIKOR method	(WiMAX) and WLAN	Throughput, Delay, Jitter and Bit Error rate regarding QoS classes.
[3]	2016	Calculate the comprehensive evaluation value for each alternative by integrating three methods: (FAHP), (SD), and (GRA). Establish a threshold and utilize it to select the most suitable target network for access,	GRA, FAHP, and standard deviation are employed.	WLAN, GPRS, UMTS, and LTE-A	The available bandwidth, latency, delay, jitter, packet loss rate, bit error rate, and service cost.
[4]	2018	service attributes and user preferences, suggests a selection algorithm for HWNs. This algorithm combines a number of techniques.	utility function, MADM, FAHP, and entropy method.	WLAN, LTE, UMTS, and WIMAX	Network load, packet loss rate, moving speed, bandwidth, network load jitter, and service price

[5]	2020	For vertical handover, a new MADM method based on weighting method and cosine similarity measure that combines SW and OW weight method has been proposed.	COSINE-Similarity, TOPSIS, and GRA	UMTS, LTE, WLAN, and WIMAX	Cost, throughput, jitter, loss rate, delay, and jitter
[6]	2020	Proposed calculates the SW of network attributes using INFAHP and obtains OW using the Coefficient of Variation (CV) at the same time. It also expresses the semantic significance of the intuitionistic normal fuzzy number. Subjective and objective weights are combined to create the final weights. Following that, IGRA can be used to sort the candidate networks.	INFAHP and IGRA.	WLAN, WIMAX, LET, and UMTS	Bandwidth, delay, jitter, packet loss rate, cost, security
[7]	2021	network selection algorithm based on fuzzy ANP-based arbitrary weights, cosine similarity distance, and particle swarm optimization-based objective weight is suggested.	PSO algorithm and cosine similarity distance	WIMAX, LET, UMTS, and WLAN	the jittery, Throughput, Load, Loss Rate, and Cost

1.5 Thesis Outlines

The thesis contains four chapters in addition to this chapter as illustrated in the following:

- **Chapter 2** This chapter overview of wireless communication networks and the process of handover. Furthermore, it illustrated of various existing network selection algorithms.

- **Chapter 3** discusses in detail the developed technique in network selection for heterogeneous wireless network environments.

- **Chapter 4** presents the implementation, results, and discussions of the developed technique for different cases. Also, it contains the evaluation and the comparison results with closely related techniques.
- **Chapter 5** contains the conclusion and suggestions for future

Chapter Two

Background and Theoretical Part

2.1 Introduction

Wireless networks have become increasingly popular due to their convenience, flexibility, and mobility. Users can access the network from anywhere within the coverage area, without a cable connecting them to a specific location. This allows for greater freedom of movement and more flexible work arrangements. This chapter represents an overview of the evolution of HWN, and particularly the key concepts of network selection. It also highlights the MADM methods. Finally, the attributes and evaluation metrics of the network are discussed as well.

2.2 Wireless Networks

The wireless networks can be classified into two categories represented by the homogeneous and the heterogeneous wireless networks that will be described in the following sub-sections.

2.2.1. Homogeneous Wireless Networks

It is characterized by having a uniform infrastructure and coverage area. In other words, all the devices in the network use the same communication technology, operate on the same frequency band, and are deployed in a similar environment Figure 2.1 shows an example of homogeneous wireless network [9].

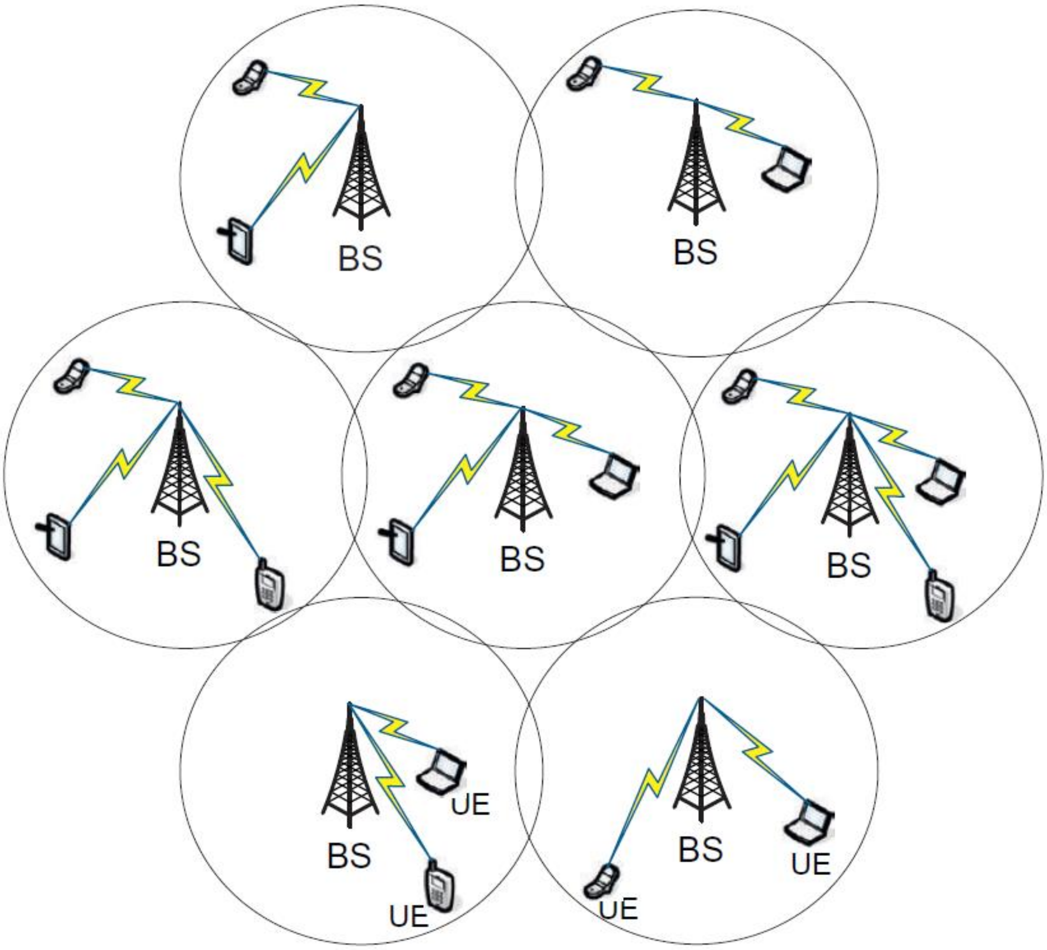

Figure 2.1: Homogeneous Wireless Network Example [9].

2.2.2. Heterogeneous Wireless Networks

The HWN composed of multiple types of devices that use different communication technologies and operate on different frequency bands. These networks are often deployed in environments where coverage is a challenge, such as in outdoor areas. Examples of HWN include ad hoc networks, satellite networks, and cellular networks [10]. Figure 2.2 shows an example of HWN.

In a heterogeneous wireless access system, various service providers operate different access networks, each governed by their respective service agreements, in order to provide uninterrupted service to mobile users and optimize their own utilities. Meanwhile, the mobile users would like to maintain the best network connectivity possible by seamlessly and dynamically switching between these different access networks [12], [13].

The main differences between these two types of networks are their infrastructure, coverage area, and deployment scenarios. The choice of network type depends on the specific deployment scenario and the needs of the users. Homogeneous networks are generally easier to deploy and manage, and can provide high-speed connections over short distances. Heterogeneous networks, on the other hand, can provide wider coverage and better mobility support, but may require more complex infrastructure and management [14].

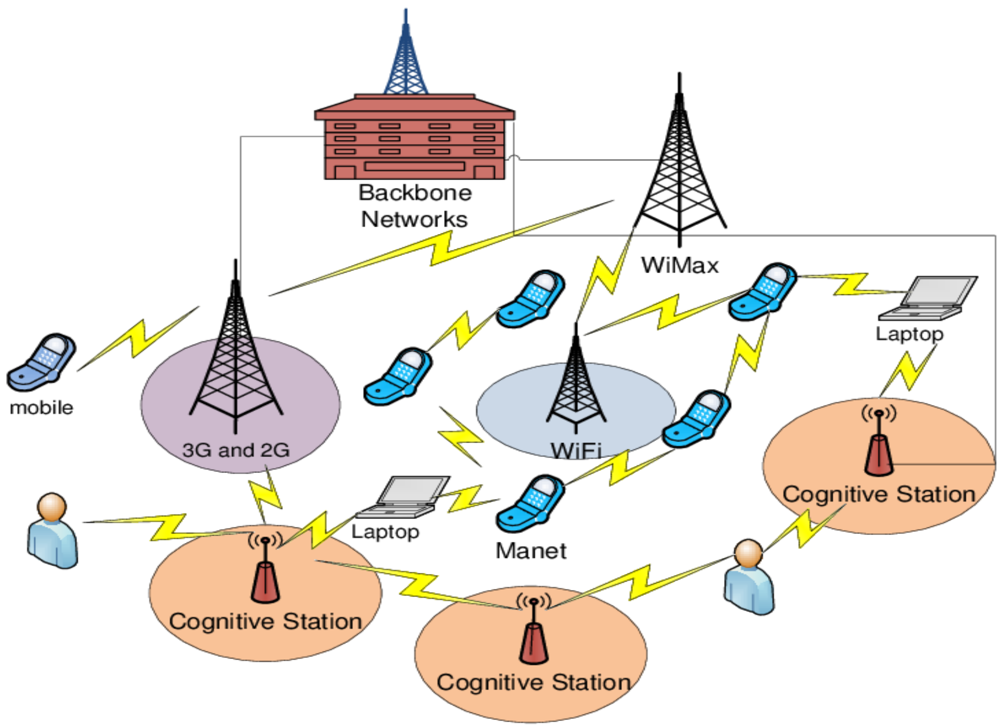

Figure 2.2: Heterogeneous Wireless Network Example [14].

2.3. Issues in Heterogeneous Wireless Networks

Several unresolved issues have the potential to impact the motivation for HWNs [7].These issues may be grouped into various categories; each issue being discussed in detail in the following subsections:

2.3.1. The Common Billing Platform Challenge

One common billing platform issue in HWN is the complexity of billing and charging customers for services that are provided by multiple network operators. Heterogeneous wireless networks are composed of different types of networks, such as Wi-Fi, cellular, and satellite, that are owned and operated by different providers.

In such networks, customers may use different networks for different services, or switch between networks depending on their location, device capabilities, and service availability. This creates challenges for billing and charging, as the usage of each network needs to be accurately tracked and billed to the customer [15].

2.3.2. Integration of Radio Access Technologies (RATs)

To achieve integration of RAT in heterogeneous wireless networks, it is important to ensure that different RATs can interoperate and complement each other to provide a seamless user experience. This can be achieved through various mechanisms, such as network selection algorithms, handover procedures, and resource allocation mechanisms.

Network selection algorithms: Network selection algorithms are used to select the most suitable network based on various criteria such as signal strength, available bandwidth, and cost. The algorithms can be designed to prioritize certain networks over others based on the user's preferences and the availability of network resource.

Handover procedures: Handover procedures allow users to switch between different networks seamlessly without interrupting the service.

Resource allocation mechanisms: Resource allocation mechanisms are used to allocate network resources such as bandwidth and spectrum to different users and applications [16], [17].

By achieving high integration RAT in heterogeneous wireless networks, users can benefit from a seamless and uninterrupted connectivity experience, regardless of the RAT they are using, which ultimately leads to better user experience and satisfaction.

2.3.3. Service Continuity

The ability of a user to maintain a consistent level of service as they move between different types of wireless networks, such as Wi-Fi, cellular, and satellite networks. The goal of service continuity is to provide a seamless and uninterrupted user experience, regardless of the network the user is connected to. Service continuity is a critical aspect of heterogeneous wireless networks, as users are likely to switch between different networks depending on their location, device capabilities, and service availability [17]. To ensure service continuity, several mechanisms can be used, such as Vertical handover, Horizontal handover, Session continuity, and QoS continuity. By ensuring service continuity in heterogeneous wireless networks, users can enjoy a seamless and uninterrupted experience, regardless of the network they are connected to, which ultimately leads to better user experience and satisfaction.

2.4. Radio Access Technology (RAT)

There are different technologies for RAT as follows:

2.4.1. Long-Term Evolution (LTE)

LTE is a mobile phone network type idea that was first introduced. NTT DoCoMo in 2004 The discussion on the topic continued until 2009, Even though TeliaSonera provided service of LTE to its consumer as an official offering. It improves the speed and data transmission capabilities of various networks making it important because of offers performance improvements up to 50x or more from Improving Spectral Efficiency in

Cellular Networks. The primary objective of LTE is to provide a radio access technology that offers high data rates, low latency, and optimized packet delivery while accommodating flexible bandwidth deployment. Additionally, network architecture is designed for support packet-switched traffic, ensuring smooth mobility and superior QoS [24]. The structure of LTE is shown in Figure 2.3.

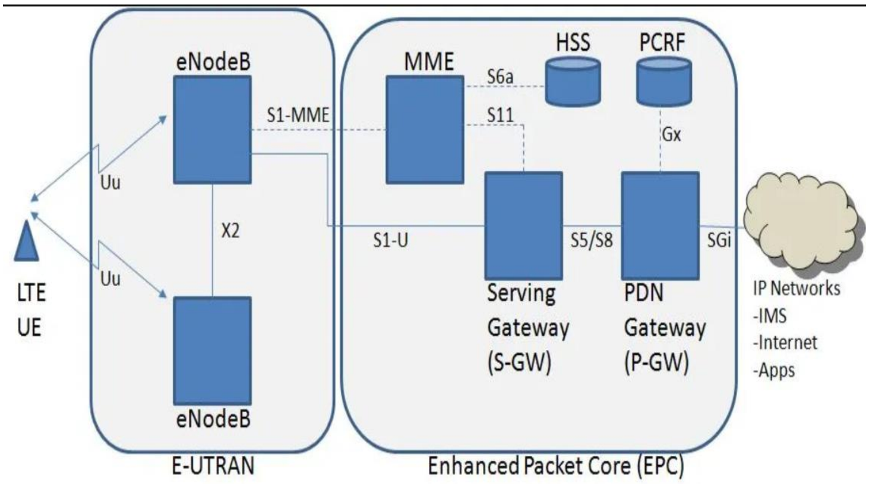

Figure 2.3: The component of LTE [24].

The structure of LTE consists of :

- **eNodeB -Evolved Node B**: This is the main component that allows users to connect to the network.

- **MME – Mobility Management Entity :**The MME is responsible for initiating paging and authentication of the mobile device.

- **S-GW-Serving Gateway** : The S-GW is responsible for keeping track of devices when they move between eNobeB’s.

-P-GW : This is what connects the LTE network to the Capital I Internet.

Other terms: S1 interface , X2 interface provides connectivity between two or more eNodeBs

2.4.2. Universal Mobile Telecommunication Service (UMTS)

It is Developed by the European Telecommunications Standards Institute (ETSI), a set of standards for the global market, this will be a truly global 3G mobile communication system, adding new features and introducing technological innovations. UMTS, 3G for Wireless Mobile Systems, LTE has transformed into a multimedia network, offering wireless broadband connectivity with high data rates that allow UMTS network users to leverage advanced online applications and stream video content from various devices Wireless Broadband UMTS [13].

UMTS provides mobile computer and cell phone users with a unified set of location-independent services. UMTS technology is built on the foundation of the widely-used GSM communication standard. With the advent of UMTS, users of computers and mobile phones can stay connected to the Internet and access the same functions no matter where they are. To access the Internet, users rely a combination of terrestrial radio and satellite communications. UMTS provides a packet-switched connection using the Internet Protocol (IP), which ensures that a virtual circuit is always accessible [25]. Figure 2.4 shows the content of UMTS structure:

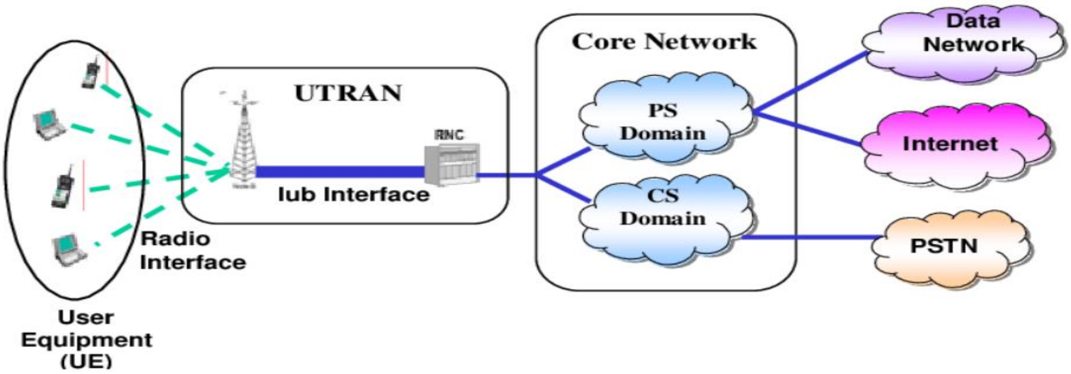

Figure 2.4: The component of UMTS [14].

-The user equipment: The user equipment is divided into the mobile station, the SIM card, universal subscriber identity module or (U-SIM).

-The access networks: The access network consists of towers to which the mobile station connects.

- **The radio network controller (RNC)**: This is where the intelligence of the access network lies. It processes the data from Node B connected to it.

- The core networks: This is the backbone network. It consists of a circuit-switched (CS) domain and packet-switched (PS) domain[14].

2.4.3. Wireless-Fidelity (Wi-Fi)

Wireless networks are used to connect multiple computers in the house to each other without need to use wires that restrict movement.

Wi-Fi technology has a lot of benefits and advantages, as it is a cheap technology that is easy to set up and use. It's also not visible unless you have a PC and it detects WiFi in the area so you can use it if you're allowed to. A wireless network uses radio waves just like mobile phones, televisions, and radio [7]. In fact, wireless communication is similar to a two-way radio, and here is an explanation of what exactly is happening:

The wireless device connected to the computer performs the function of converting the data into a radio signal that it sends through a special antenna. A wireless router receives and encodes this signal. Then it sends it to the Internet using an Internet connection cable via an Ethernet connection [26].

In WiFi, information can be sent over 3 different frequency bands or using frequency hopping technology between the three different frequencies.

Frequency hopping technology helps reduce interference that causes a group of devices to use the wireless connection at the same time.

The reverse process also takes place, where the router receives data from the Internet, converts and translates it into a radio signal, and transmits it to the computer through the wireless device that is linked to it [26].

The structure of WiFi is Wireless Client, Wireless Access Point, Router, Modem, Network Switch, Firewall. Network Cabling and Power Source

This simplified structure outlines the main components of a WiFi network and their roles in facilitating wireless connectivity and data transfer. Figure 2.5 shows the WiFi component.

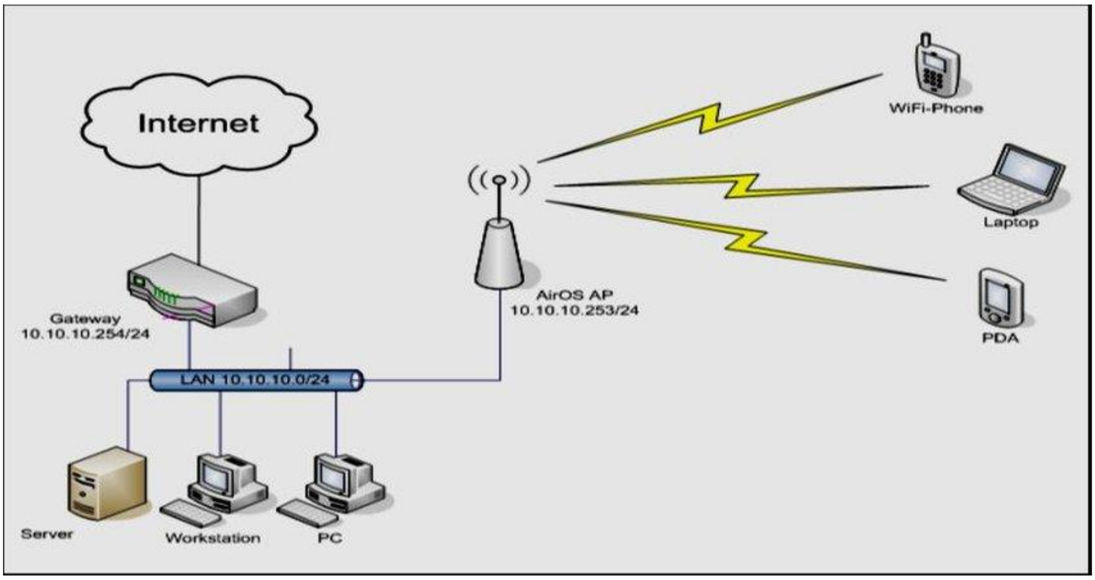

Figure 2.5: The Wi-Fi structure [25].

2.4.4. Worldwide Interoperability for Microwave Access, (Wi-MAX)

Today, when considering the modern means of Internet communication, find that there are multiple methods available. These include broadband access, which can be achieved through DSL (Digital Subscriber Line) or cable modem connections. Another popular method is Wi-Fi, which relies on wireless communication with Internet service providers. Additionally, although less common, the dial-up method is still used in situations where other means of communication are unavailable [27].

However, WiMAX, also known as 802.16, is the most innovative system that is now in use. WiMAX is a wireless technology that will eventually replace cable and DSL as the fastest method of connecting to the Internet.

WiMAX technology offers extended coverage over long distances and provides high-speed Internet access. It has the capability to serve a large number of users simultaneously. Additionally, one of the advantages of WiMAX is that it can reach individuals who do not have access to telephone services or cable Internet, expanding connectivity options to a broader population.

The WiMAX system consists of two primary components as shown in Figure 2.6:

WiMAX Tower: Similar to transmission towers found in mobile phone networks, WiMAX towers serve as the infrastructure for the WiMAX network. Each WiMAX tower has an extensive coverage area, capable of spanning up to 8,000 square kilometers. These towers are responsible for transmitting and receiving WiMAX signals, enabling communication with WiMAX-enabled devices.

WiMAX Receiver: The WiMAX receiver is necessary for devices to connect to WiMAX network and access its services. This receiver, along with its antenna, can be integrated into laptop computers, similar to Wi-Fi technology. Alternatively, it can take the form of a PCMCIA card that is inserted into a computer's expansion slot. The WiMAX receiver captures the WiMAX signals and facilitates the establishment of a connection between the device and the WiMAX network [28].

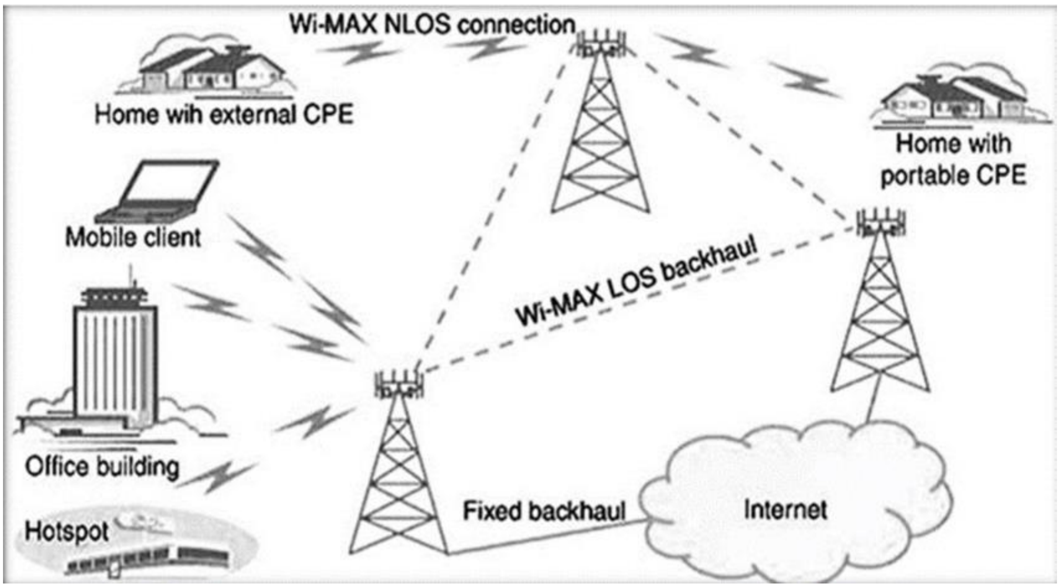

Figure 2.6: Wi-MAX structure [26].

2.5. Multiple Attribute Decision-making (MADM)

MADM is one of the first-rate methodologies used for the selection of networks in heterogeneous wireless networks. The values of all parameters under monitoring are inputted to MADM first, then these values are normalized, and each attribute is measured depending on its weight [3], [10]. After that, the alternative networks are rated. The MADM has a lot of variants, several techniques are utilized in the selection of optimal radio access in HWNs with mobile devices These techniques include TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), GRA (Grey Relational Analysis), VIKOR (Multi-Criteria Optimization and Compromise Solution), and various others. These techniques support evaluation and determining the most suitable network option based on multiple criteria and preferences [29].

2.5.1. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS is efficient and simple multiple-criteria method presented by Hwang and Yoon for identifying solutions from a finite set of alternatives developed in 1981. The TOPSIS method is based on the principle that the ideal alternative is choose the greatest geometric distance from the negative ideal solution and the shortest geometric distance from the positive ideal solution. This approach involves the process of comparing a set of alternatives that assigning weights to each criterion, normalizing scores for each criterion, and calculating the geometric distance between each alternative and the ideal alternative, which achieves the highest score in each criterion. Some of the characteristics that distinguish it from other methods include ease of application and distance consideration to an ideal solution, However, The TOPSIS method has certain limitations, one of which is the potential for rank reversal. the rank reversal occurs when the order of preference among alternatives changes upon the addition or removal of an alternative from the decision problem. This behavior is not always desirable or acceptable in decision-making scenarios [30].

The algorithm for selecting the optimal network follows a series of steps. It begins by creating a multi-criteria decision matrix that encompasses all relevant criteria. The normalization approach is then employed to standardize the different criteria, ensuring comparability. Next, weights are assigned to each criterion based on their relative importance. Lastly, the algorithm calculates the score for each network alternative based on the weighted criteria, enabling the determination of the optimal network choice [5].

The initial step, involves identifying the set of selection attributes and alternatives. A decision matrix, denoted as M, is then created with L rows and K columns where L is the number of Networks and K is the number of attributes. The X rows represent the candidate networks, while the Y columns represent the criteria used for evaluation [7].

$$M_{ij} = \begin{bmatrix} m_{11} & m_{12} \dots\dots\dots m_{1K} \\ m_{21} & m_{22} \dots\dots\dots m_{2K} \\ . & . \quad \dots\dots\dots \quad . \\ . & . \quad \dots\dots\dots \quad . \\ m_{L1} & m_{L2} \dots\dots\dots m_{LK} \end{bmatrix} \quad (2.1)$$

- Use the Euclidean distance approach, and compute the normalized decision matrix N_{ij} .

$$N_{ij} = \frac{M_{ij}}{\sqrt{\sum_{j}^{k} M_{ij}^{2}}} \quad (2.2)$$

- Based on the weight (w) for each item in normalized decision matrix N_{ij} to obtain weighted normalized decision matrix

$$W_{ij} = w_j * N_{ij} \quad (2.3)$$

Where w reflects item importance and $\sum_{j=1}^{K} w_j = 1$

- Determine optimal solution I+ and the negative optimal solution I−:

$$I^{+} = [W_1^{+}, W_2^{+}, W_3^{+}, \dots\dots, W_K^{+}]$$

$$(2.4)$$

$$I^{-} = [W_1^{-}, W_2^{-}, W_3^{-}, \dots\dots, W_K^{-}]$$

- For cost criteria

$$I_j^+ = \min W_{IJ}$$

(2.5)

$$I_j^- = max\ W_{IJ}$$

- For benefit criteria

$$I_j^+ = \max W_{IJ}$$

(2.6)

$$I_j^- = \min W_{IJ}$$

- Calculate similarity distances between I+ and I− as follows:

$$SD_i^+ = \sqrt{\sum_{j=1}^{K} (I_j^+ - W_{ij})^2}$$

(2.7)

$$SD_i^- = \sqrt{\sum_{j=1}^{K} (W_{ij} - I^-)^2}$$

- Calculate the relative closeness to the optimal solution:

$$R_i^* = \frac{SD_i^-}{SD_i^+ + SD_i^-} \quad (2.8)$$

- The network with the greatest R_i^* value is chosen after categorize alternatives as a decreasing function R_i^* value.

$$Best\ select = Arg(\ max\ R_i^*) \quad (2.9)$$

2.5.2. Grey Relational Analysis (GRA)

GRA is a technique for making decisions that takes into account multiple criteria and used to evaluate the relationships among different factors in a system. It is a mathematical tool that is often used in engineering, management, and social sciences to analyze complex systems with multiple variables [33].

GRA relies on the principles and foundations of grey theory. Which uses a small amount of data to analyze and predict the behavior of a system. In GRA, each factor or criterion is represented by a time series of data, and the relationship between each factor is evaluated by calculating the level of grey relation between them [7].

The process of GRA involves several steps, including data normalization, the construction of a reference series. The calculation of the grey correlation degree and the subsequent ranking of factors based on their grey correlation degree enable the identification of key factors or criteria within a system. These results from GRA provide valuable insights into the relationships between these factors, aiding in informed.

GRA has several advantages over other decision-making methods, including its ability to handle incomplete and uncertain data, its simplicity and ease of use, and its ability to provide a quantitative assessment of the relationships between different factors in a system. However, it also has some limitations, including its sensitivity to the selection of the reference series and the need for a large amount of data to achieve accurate results . The steps in the procedure are as follows:

- Determine decision matrix M
- Create the normalized decision matrix N using the Max-Min method hence, normalized value of N derived:
    - For benefit criteria:

$$N_{ij} = \frac{M_{ij} - M_j^{min}}{M_j^{max} - M_j^{min}} \tag{2.10}$$

    - For cost criteria

$$N_{ij} = \frac{M_j^{max} - M_{ij}}{M_j^{max} - M_j^{min}} \tag{2.11}$$

- Determine the positive ideal solution I^{+}
  - For benefit criteria:

$$I^{*} = maxN_{ij} \tag{2.12}$$

  - For cost criteria:

$$I_j^{*} = minN_{ij} \tag{2.13}$$

- From the positive ideal solution, compute the grey relational coefficient (GRC) of each choice as a fallowing step:
  - Define Δ^{i} where

$$\Delta^{i} = \left|I_j^{*} - N_{ij}\right|$$

  - Define Δ_{max} , Δ_{min} where

$$\Delta_{max} = min\Delta^{i} \quad , \quad \Delta_{min} = min\ \Delta^{i}$$

  - the identification coefficient $\rho = 1$
  - the grey relational coefficient is:

$$GRC_{ij} = \frac{\Delta_{min} + P * \Delta_{max}}{\Delta^{i} + P * \Delta_{max}} \tag{2.14}$$

- Using the following equation, Compute the degree of grey relational coefficient for each option with respect to the positive ideal solution.

$$GRC_i^{*} = \sum_j^{i} W_j * GRC_{ij} \tag{2.15}$$

  Where W_j reflects item importance
- Ranking the alternatives: arranging the alternatives in a specific order. by decreasing GRC_i^{*} the network values, with the greatest value will be selected

$$best\ select = Arg(max(GRC_i^{*})) \tag{2.16}$$

2.5.3. VlseKriterijumska Optimizacija Kompromisno Resenje (VIKOR) multi-criteria optimization and compromise solution

VIKOR is an approach for making decisions that involve multiple criteria, aiming to identify the optimal choice among various alternatives. It finds applicability in wireless network selection, where VIKOR aids in determining the most suitable network connection by considering factors like signal strength, data rate, and network availability [2].

VIKOR operates by computing the compromise solution, which refers to the alternative that choose the closest proximity to the ideal solution while being the farthest away from the worst solution. The ideal solution represents the alternative that attains the highest scores across all criteria, while the worst solution corresponds to the alternative with the lowest scores across all criteria. VIKOR takes into account both the distance from the ideal solution and the distance from the worst solution to determine the compromise solution [7].

The VIKOR process involves several steps, including the normalization of the criteria values, the calculation of the weighted normalized scores for each alternative, the identification of the ideal and worst solutions, the calculation of the distance from the ideal and worst solutions for each alternative, and the determination of the compromise solution.

VIKOR has several advantages over other decision-making methods, including its ability to handle conflicting and incomplete criteria, its simplicity and ease of use, and its ability to provide a quantitative assessment of the alternatives. However, it also has some limitations, including its sensitivity to the selection of weights for the criteria and the potential for subjectivity in the determination of the ideal and worst solutions.

The formulation of the VIKOR technique is as follows:

- Prepare the matrix of decision M
- normalized value

$$N_{ij} = \frac{M_{ij}-M_j}{M_{maxj}-M_{minj}} \quad (2.17)$$

Where:

- M_{ij} is the value of the alternative for the criterion,
- $M_{min\,j}$ is the minimum value of the criterion
- $M_{max\,j}$ is the maximum value of the criterion.

- Weighted normalized score equation:

$$V_{ij} = w_j \times N_{ij} \quad (2.18)$$

where w_j is the weight assigned to the criterion and N_{ij} is the normalized value of the alternative for the criterion.

- Determination of ideal solution:

$$S_I^* = MAX\, V_{ij} \quad (2.19)$$

where S_I* is the ideal solution and V_{ij} is the weighted normalized score for the alternative.

- Determination of worst solution:

$$S_I^- = Min\, V_{ij} \quad (2.20)$$

where S_I- is the worst solution and V_{ij} is the weighted normalized score for the alternative.

- Distance from the ideal solution:

$$Si^{+} = \sqrt{\sum \ (V_{ij} - V_{ij}^{*})\ ^\wedge 2} \qquad (2.21)$$

- Distance from the worst solution:

$$Si^{-} = \sqrt{\sum \ (V_{ij} - V_{ij}^{-})\ ^\wedge 2} \qquad (2.22)$$

- Calculation of the relative closeness to the ideal solution:

$$Q_i = \frac{S_i^{-} - S_i^{*}}{S_i^{-} - S_i^{+}} \qquad (2.23)$$

- Ranking of the alternatives:

The alternatives are ranked based on their Q_i values, with the alternative that has the min Q_i value being the compromise solution.

Best select = Arg(min Q) (2.24)

2.6. Network Attributes and Evaluation metrics

The network attributes or network resources used in the selection process to compare between the performance of the selection methods are described as follows:

2.6.1. Delay in network

Delay is indicating the duration that takes for data packets to travel from one network location to another. It is usually quantified in milliseconds (ms) and can be influenced by various factors, including the distance between endpoints, network speed, the number of devices and network components involved in the transmission, and the volume of data being transferred [21].

Network delay can have a significant impact on the performance of network-based applications, particularly those require real-time communication such as online gaming or video conferencing. Higher network delay can result in observable delays in data transmission, leading to slower response times, lower video or audio quality, and an overall degraded user experience [36]. The delay has several parts as illustrated in Figure 2.7:

- Processing delay – the duration of processing the packet header by the router.
- Queue delay – a packet's duration in routing queues
- Transmission delay – the time it takes for a packet's bits to be sent to a link.
- Propagation delay – when the signal will show at the destination.

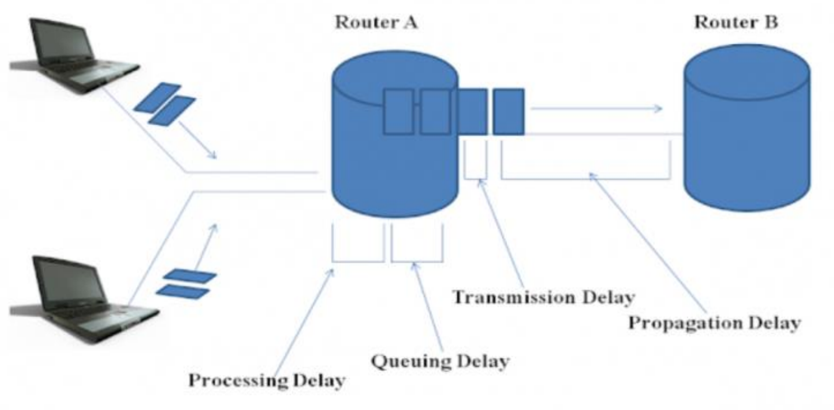

Figure 2.7: Types of Delays in Networks [21].

2.6.2. Network Jitter

Network jitter is the variation in the delay of the arrival time of packets within a network. In other words, it is the deviation in the time taken for data packets to reach their destination due to varying network conditions such as congestion, routing changes, or transmission errors [37].

Jitter is often measured in milliseconds (ms).It can negatively affect the quality of real-time applications such as VoIP, video conferencing, or online gaming, as it can cause issues such as audio or video distortion, dropped calls, or lag. To reduce jitter, network administrators can prioritize traffic, implement QoS policies, use buffering, and optimize routing to ensure that packets arrive at their destination within an acceptable time frame [21].

2.6.3. Packet Loss Rate

Network packet loss rate refers to the percentage of data packets that do not reach their intended destination within a network. Packet loss can occur due to a variety of reasons, including network congestion, transmission errors, faulty network hardware, or routing issues [38].

Packet loss can negatively impact network performance, particularly for real-time applications that require low latency and high reliability, such as voice and video communication or online gaming. When packets are lost, the receiver may experience gaps in audio or video, distorted sound or images, or delayed responses [39].

To monitor and reduce packet loss rate, network administrators may use network monitoring tools to identify areas of high packet loss and address any underlying issues. They may also use techniques such as packet buffering, retransmission, or redundancy to ensure that packets reach their destination even in the event of packet loss.

2.6.4. Throughput

Network throughput refers to the volume of data that can be transferred over a network within a specific time interval. It is commonly quantified in units of bits per second (bps).It represents the actual speed of data transfer between network devices.

Throughput can be affected by various factors, such as network congestion, packet loss, latency, or network hardware limitations. In addition, different network protocols and technologies have different maximum throughput rates, depending on their design and implementation [41].

To optimize network throughput, network administrators may use techniques such as traffic shaping, load balancing, or QoS policies to prioritize network traffic and ensure that critical applications have sufficient bandwidth. They may also upgrade network hardware or implement more efficient network protocols to improve network performance. Network throughput is an important metric for measuring the efficiency and capacity of a network, and it plays a critical role in determining the overall performance of network-based applications and services [44].

2.6.5. Network Cost

To manage network costs, organizations may use various strategies, such as optimizing network hardware and software to reduce power consumption, using open-source or cloud-based solutions to reduce licensing fees, and implementing cost-effective security and management tools [21], [45].

2.6.6. Handover

It also known roaming, handover refers to the procedure of moving an ongoing communication session from one wireless access point to another within a wireless network without interrupting the session [10].This is typically necessary when a user move within the coverage area of a wireless network and the signal strength or quality changes [15].Wireless network handovers can occur between different access points within the same network, or between different networks such as cellular networks and Wi-Fi networks. The handover process can be initiated automatically by the network or manually by the user, and it can be seamless or involve a brief interruption in the communication session. Seamless handovers require careful coordination between the network and the user device to ensure that the session is not disrupted. The handover process typically involves several steps, including signal strength monitoring, load balancing, and intelligent handover algorithms. These techniques help to ensure that the user experiences a smooth transition between access points, and that the session remains uninterrupted. To ensure optimal handover performance, wireless networks may use various techniques such as optimizing network coverage, deploying more access points, or implementing intelligent handover algorithms [47].There are types of handovers that can be distinguished based on the entity that initiates the handover:

1. Mobile-Assisted Handover (MAHO): In this type of handover, the mobile device provides information about neighboring access points to the network, which then decides when to initiate a handover based on the received information.

2. Network-Assisted Handover (NAHO): In this type of handover, the network provides information about neighboring access points to the mobile device, which then decides when to initiate a handover based on the received information [8].

Here are also commonly used classifications of handover based on mobility scenarios:

• **Horizontal Handover** In a wireless network, horizontal handover occurs whenever a mobile device moves between different access points or base stations within the same network. This is commonly seen in Wi-

Fi networks, where a mobile device may move between different access points within the same Wi-Fi network. The handover process is initiated when the signal strength from the current access point decreases, and the mobile device starts scanning for neighboring access points with stronger signals [18], [22].

Horizontal handover is important in wireless networks to ensure that the mobile device maintains a strong and stable connection to the network, even as it moves around within the coverage area.

• **Vertical Handover** Vertical handover is occurring when user node or mobile device moves between different access points that operate on different radio access technologies or different frequency bands. This type of handover is also referred to as inter-system handover.

This handover process is typically more complex than a horizontal handover, as it involves switching between different types of networks with different characteristics [48].

The handover process in a vertical handover typically involves the mobile device scanning for neighboring networks, selecting the most appropriate network based on signal strength, quality, and other factors, and then initiating the handover process with the new network. The handover process may involve additional steps such as authentication, authorization, and accounting before the mobile device is fully connected to the new network.

Vertical handover is important in wireless networks to ensure that the mobile device maintains a connection to the network as it moves around, even as it switches between different types of networks. By optimizing the handover process, network operators can improve network performance and provide a seamless user experience for mobile device users [46].

2.7. The Coverage Range

The coverage range of a wireless network is the farthest distance at which two antennas may communicate with one another. as shown in Figure 2.8. In a heterogeneous wireless network, the coverage range can vary depending on several factors, including the type of wireless technology used, the frequency band, the transmit power of the base stations or access points and the channel noises [49], [50] .The coverage range (C*R*) can be calculated according to this equation:

$$CR = \left(\frac{c}{2\pi * f}\right) * \sqrt{\frac{Pt}{Pr}} \quad (2.24)$$

where Pt and Pr stand for the respective transmitted and received powers. The operating frequency is f, and c is the speed of light.

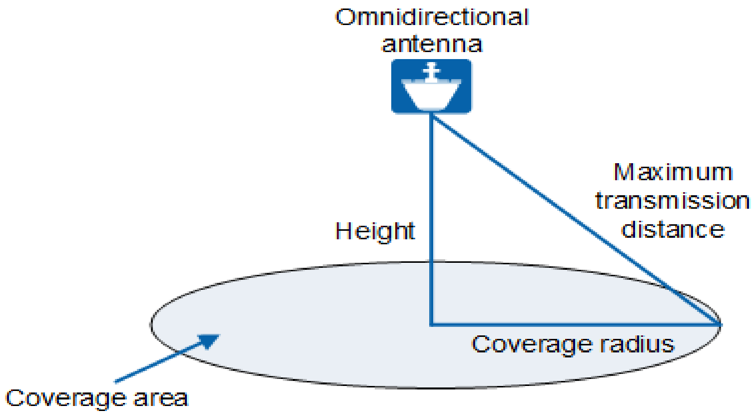

Figure 2.8: The coverage Range of the wireless network [46].

2.8. Ensemble Average

An ensemble refers to the combination of multiple models to make predictions or decisions. To create an ensemble average in network selection, the decisions or predictions from each model are combined using an averaging approach as shown in Figure 2.9.

The averaging process can be done in different ways, depending on the specific requirements of the network selection problem. It could involve averaging the probabilities or confidence scores assigned by each model, or taking a majority vote based on the predicted network labels [50].

By using an ensemble average in network selection, you can combine the advantages of several models and reduce the influence of any one model's biases or limitations. This can result in more robust and accurate network selection decisions, improving the overall performance and user experience in wireless communication systems [52].

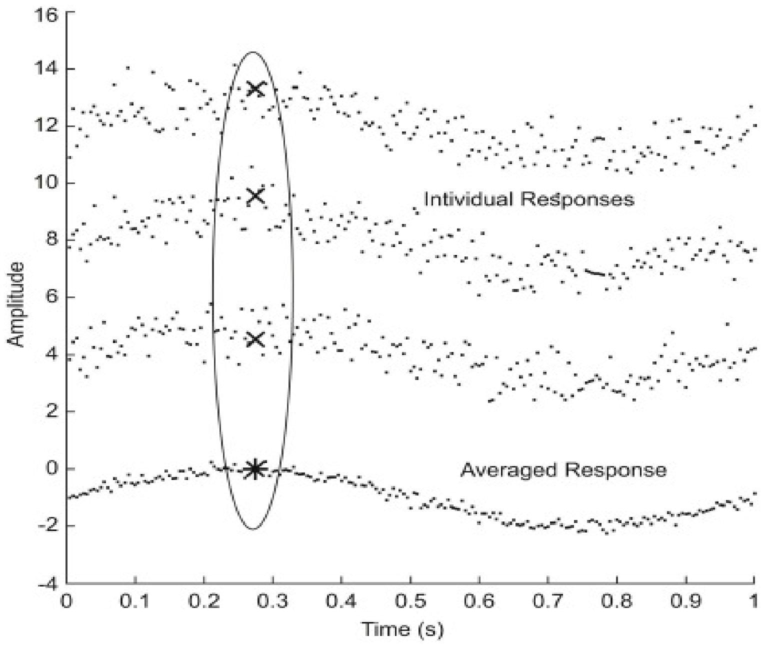

Figure 2.9: The Ensemble Average Example [50].

2.9. Summary

In this Chapter, the theoretical framework is established to provide a comprehensive understanding of the concepts, theories, and models that underpin. The key components of the theoretical part are summarized as follows: the types of wireless networks, most of the problems facing wireless networks and what is the reason that led to the use of selection algorithms, set of networks and the structure of each network. Also, group of the attributes used in the research, which is affected by each network. The three MADM methods and their equations, handover and its types. Finally, the Ensemble Average and the coverage range and how to calculate.

Chapter Three

The Proposed System

3.1 Introduction

This chapter presents the developed technique that is used to select the network in heterogeneous wireless network environments. This technique is based on the aforementioned MADM techniques and the ensemble average to increase the reliability in the selection process. Section two describes the developed method's general block diagram. The details of the developed technique will be presented in section three.

3.2 The Proposed method's general block diagram.

Block diagram of the proposed system that shows in Figure 3.1. The Figure is illustrating the main stages of this work starting with the input stage where the attributes of each network are chosen randomly and fed to the second stage where three methods of MADM are applied separately to select the suitable network. After that, the selection results of these three methods are fed to the third stage of the ensemble average method to select one of the candidate networks. Finally, the evaluation method is used to evaluate the proposed technique concerning the other MADM techniques.

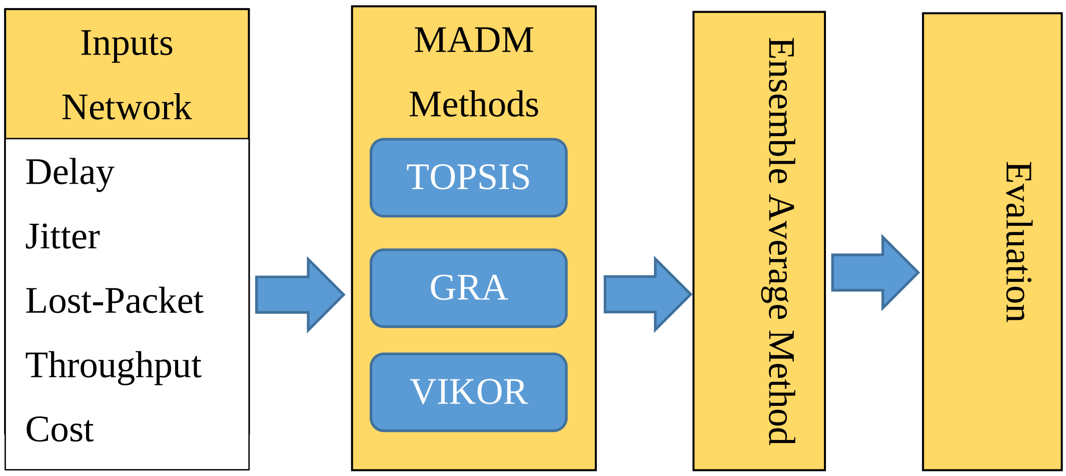

Figure 3.1: General block diagram of the proposed technique.

3.3 The Proposed Method

The flowchart of the Proposed Method is shown in Figure 3.2. The main idea of the Proposed Method is represented by the combination of three MADM methods (GRA, TOPSIS, VIKOR) with the ensemble average. The first step is the selection of the attributes for each network. Then, these selected attributes are entered into each MADM method to select the network. Finally, the ensemble average method is applied to the selections of the MADM methods to obtain the final decision of the network selection.

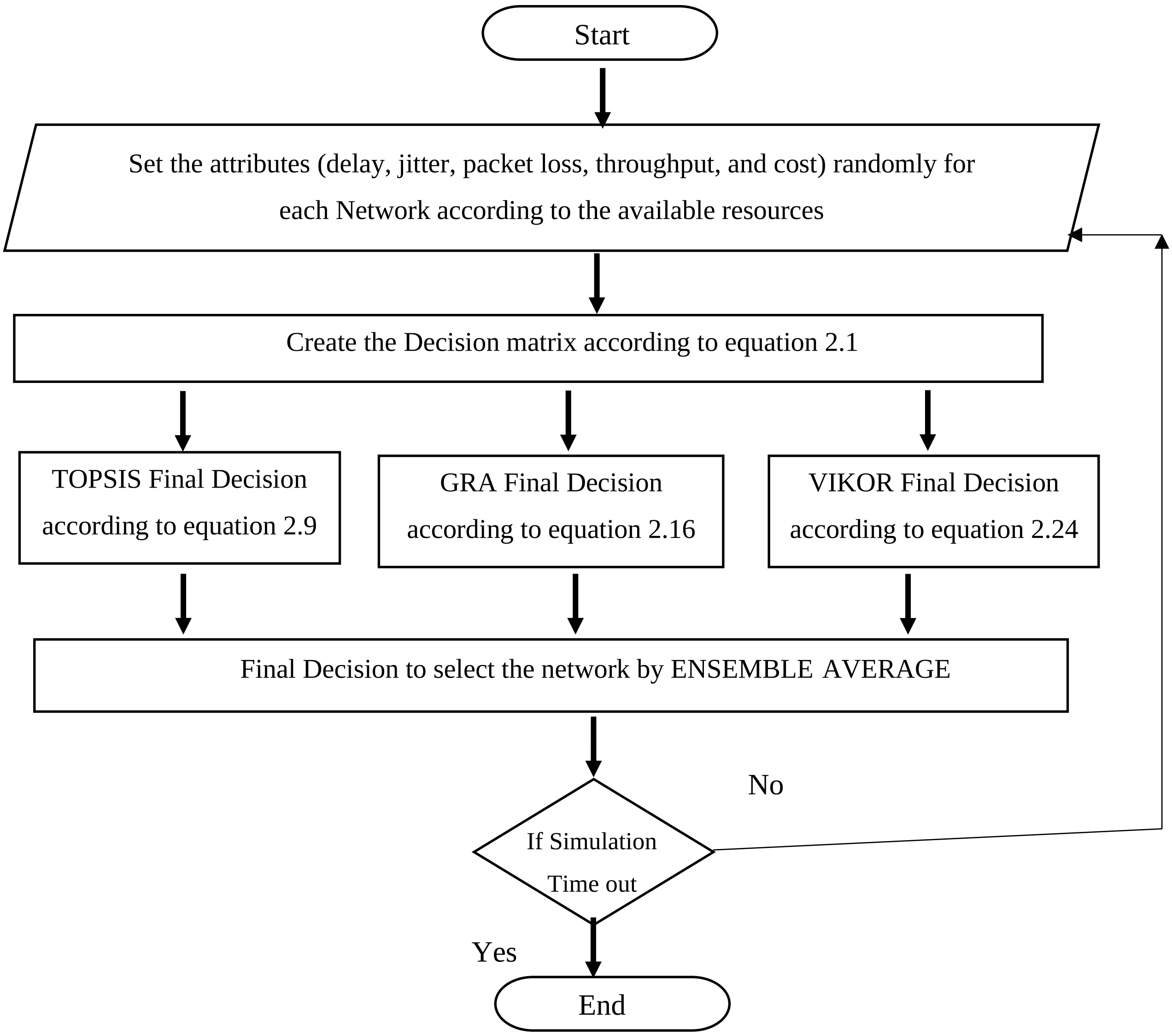

Figure 3.2: The Flowchart of the Proposed Method.

The flowchart of the Proposed Method can be divided into the following parts:

a- TOPSIS method

In this method, the candidate network that is chosen is the one that is most similar to the best-case scenario and least similar to the worst-case scenario also, the steps of this method are illustrated in the flowchart shown in Figure 3.3.

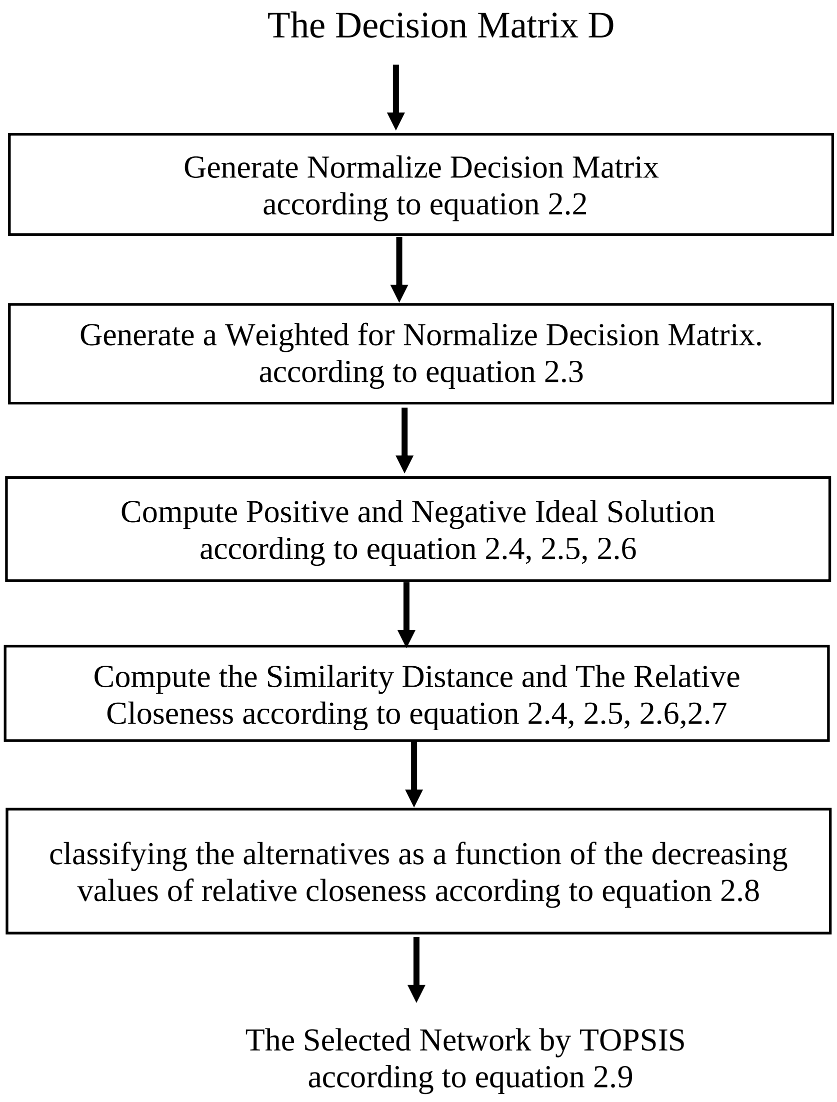

Figure 3.3: The Flowchart of the TOPSIS Method.

b- GRA method

In this method, the candidate network ultimately chooses one that most close to best-case scenario and most far to the worst-case scenario. Also, the steps of this method are illustrated in the flowchart shown in Figure 3.4.

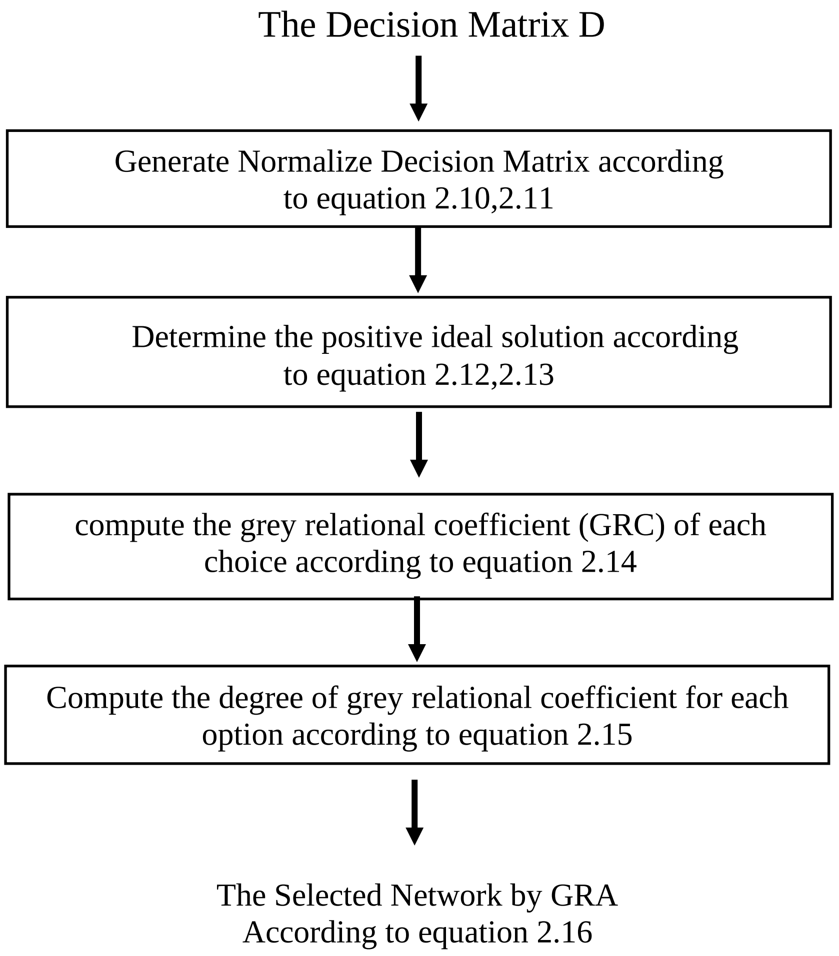

Figure 3.4: The Flowchart of the GRA Method.

c- VIKOR method

In this method, the candidate network is ultimately choosing the closest to best-case scenario and most far to worst-case scenario. Also, the steps of this method are illustrated in the flowchart shown in Figure 3.5.

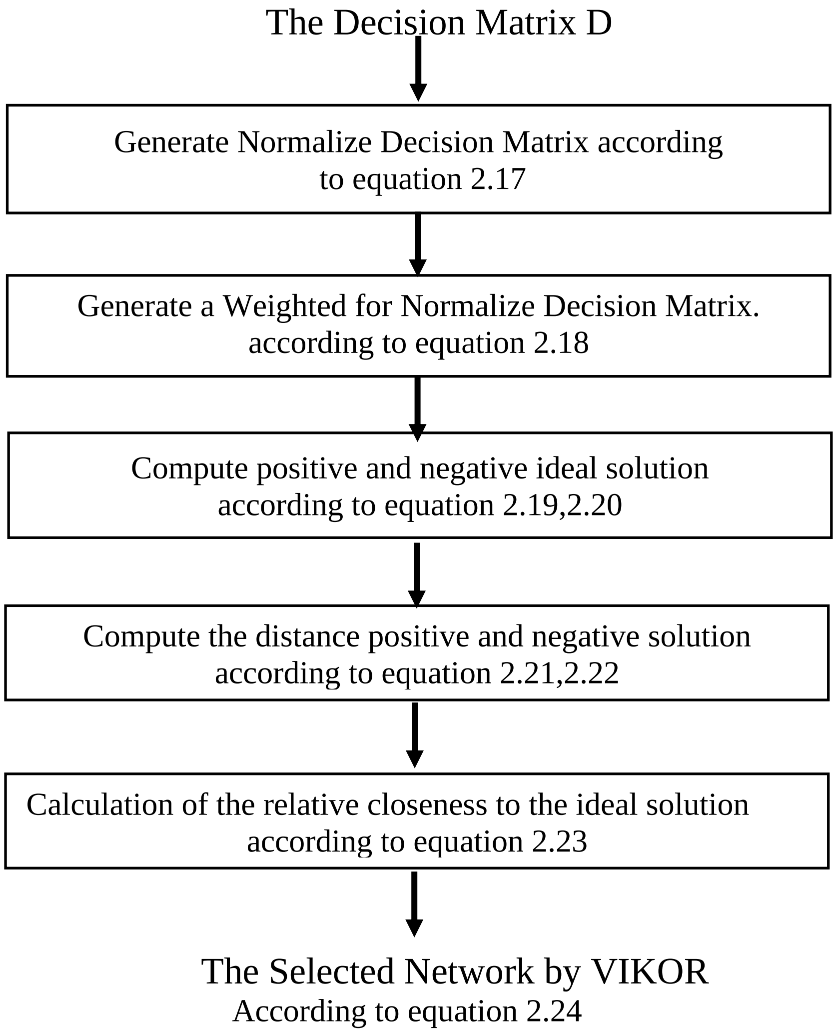

Figure 3.5: The Flowchart of the VIKOR Method.

d- The Ensemble Average Method

The ensemble average method depends on the averaging of outputs of the three methods of selection of the networks. The network with the highest average will be won (i.e. selected) as the best network. The flowchart of the ensemble average method is shown in Figure 3.6.

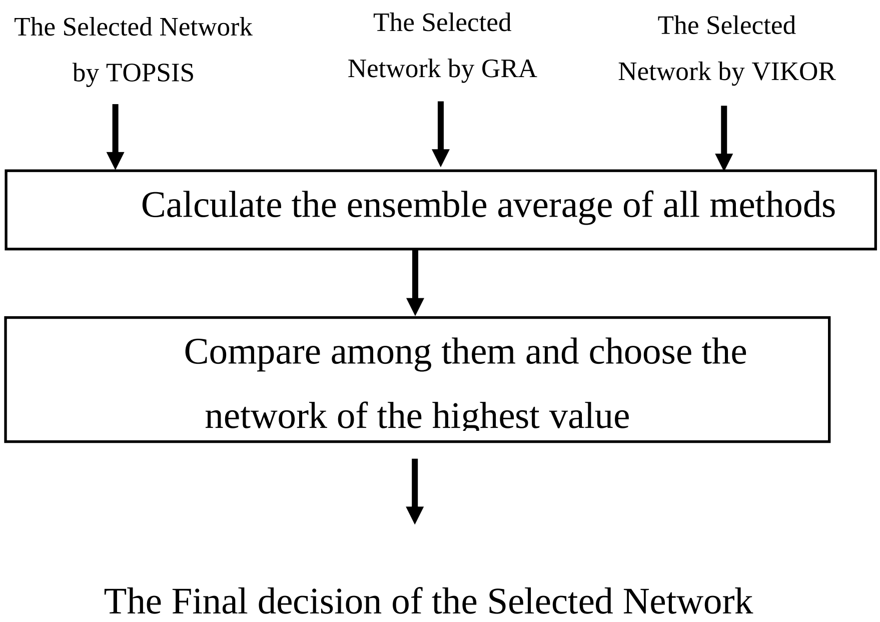

Figure 3.6: The Flowchart of the Ensemble Average Method.

For example, the TOPSIS, GRA, and VIKOR methods are used to select a network from four candidate networks (LTE, UMTS, WiFi, WIMAX), and the output scores of each method are as follows:

TOPSIS= {0.82, 0.34, 0.77, 0.15}

GRA = {0.55, 0.9, 0.26, 0.17}

VIKOR = {0.91, 0.4, 0.33, 0.28}

The ensemble average can be applied as in Table 3.1.

Table 3.1. The Ensemble Average Example.

	LTE	**UMTS**	**WiFI**	**WIMAX**	**The selected network**
TOPSIS	0.82	0.34	0.77	0.15	LTE
GRA	0.55	0.9	0.26	0.17	UMTS
VIKOR	0.91	0.4	0.33	0.28	LTE
Ensemble Average	(0.82+0.55+ 0.91)/3= 0.76	(0.34+0.9+0.4) /3= 0.546	(0.77+0.26+ 0.33)/3= 0.45	(0.15+0.17+ 0.28)/3= 0.2	LTE

Chapter Four

The Implementation and Results

4.1 Introduction

The practical part of this thesis has been implemented using MATLAB program. The specifications of the computer as follows: The hard disk is the basic storage unit in the computer and its type is solid-state drive (SSD), Random Access Memory (RAM) is the ultra-fast and temporary data storage space which is 8 GB and Central Processing Unit (CPU), which is (Intel(R) Core (TM) i5-10500H CPU @ 2.50GHz.

4.2 Simulation Setup

For the network selection problem in heterogeneous wireless networks, a new MADM-based network selection approach is created. the TOPSIS, GRA, and VIKOR algorithms of the MADM approaches, where the outputs of the three methods are inserted into an average ensemble to obtain the network selection's final decision. Let's consider the matrix consist of two-dimensions, the columns represent the 5 attributes (delay, jitter, loss rate, throughput and cost) in order, and the horizontal represents the 4 networks (LTE, UMTS, Wi-Fi, and WiMAX), in order. Table 4.1 provides the respective values for these criteria (attributes) for each access network [5], [7]. Also, the weight vector is: W = [0.1458 0.2785 0.0948 0.3614 0.1195];

Table 4.1: The Attributes Values Ranges of each Access Network.

Networks	**Delay(ms)**	**Jitter(ms)**	**Packet Loss-rate**	**Throughput (Mbps)**	**Cost ($)**
LTE	40–60	3–12	1–3	40–100	9
UMTS	25–50	5–10	1–4	1–2	3
Wi-Fi	50–150	10–20	1–7	1–54	1
WiMAX	25–60	3–10	1–5	30–80	6

In the beginning, matrix D is chosen and the calculations of each method will be based on it. Figure 4.1 shows the decision matrix D where the columns refer to 5 attribute (1 delay, 2 jitter, 3 loss rate, 4 throughput and 5 cost) and the horizontal represents the 4 networks (net1 LTE, net2 UMTS, net3 Wi-Fi, and net4 WiMAX), in order.

		Delay	jitter	packet loss-rate	throughput	cost
		1	2	3	4	5
LTE	1	54	4	1	48	9
UMTS	2	25	6	1	1	3
Wi-Fi	3	36	7	2	80	6
Wi-Max	4	94	11	6	41	1

Figure 4.1: Decision matrix D

Then a set of steps begins for decision matrix D as follows:

1- This matrix is entered using the TOPSIS method and passes through a set of equations that were mentioned in the second chapter from the equation number 2.1 to the equation number 2.9.

Figure 4.2 shows the result of equ. 2.8 in chapter 2 where in equ. 2.9 four values are obtained, each value represents the score of each network, and the highest value among these four values is the choice for the best network.

		Net 1	Net 2	Net 3	Net 4
		1	2	3	4
TOPSIS	1	0.6923	0.0062	0.9709	0.4044

Figure 4.2: Values for all networks in TOPSIS method

2- This matrix is entered according to the GRA method and passes through a set of equations that were mentioned in the second chapter, from the equation number 2.10 to the equation number 2.16.

Figure 4.3 show the result of no. 2.15 equation in chapter 2 Where in equation No. 2.16 four values are obtained, each value represents a network of networks, and the highest value among these four values is the choice for the best network.

		Net 1	Net 2	Net 3	Net 4
		1	2	3	4
GRA	2	0.6557	0.5317	0.7574	0.8208

Figure 4.3: Values for all networks in GRA method

3- This matrix is entered according to the VIKOR method and passes through a set of equations that were mentioned in the second chapter, from the equation number 2.17 to the equation number 2.24.

Figure 4.4 show the result of equ. 2.23 in chapter 2 where in equ. 2.24 four values are obtained, each value represents the score of each network, and the lowest value among these four values is the choice for the best network.

		Net 1	Net 2	Net 3	Net 4
		1	2	3	4
VIKOR	3	0.4465	0	0.9119	0.9524

Figure 4.4: Values for all networks in VIKOR method

4- The average is found for the first network, the second network, the third network, and the fourth network for all three methods (TOPSIS, GRA and VIKOR) and then find the average for them through an Ensemble Average. Figure 4.5 shows the final values for each method that is chosen from, where the selection goes to the highest value of these four networks, which is the best network in the example 0.8801 that means net three (Wi-Fi) is the best network.

	Net 1	Net 2	Net 3	Net 4
	1	2	3	4
Ensemble method	0.5982	0.1793	0.8801	0.7259

Figure 4.5: Values of ensemble average for all networks

The implementation of the proposed method consists of two scenarios as follows in the next sections:

4.3. Fixed Node Scenario

The first scenario assumes that the user's node is fixed in one place (i.e. no movement) where it receives signals from all networks, and selects one of them. Figure 4.6 demonstrates the selected network in each trail for all techniques.

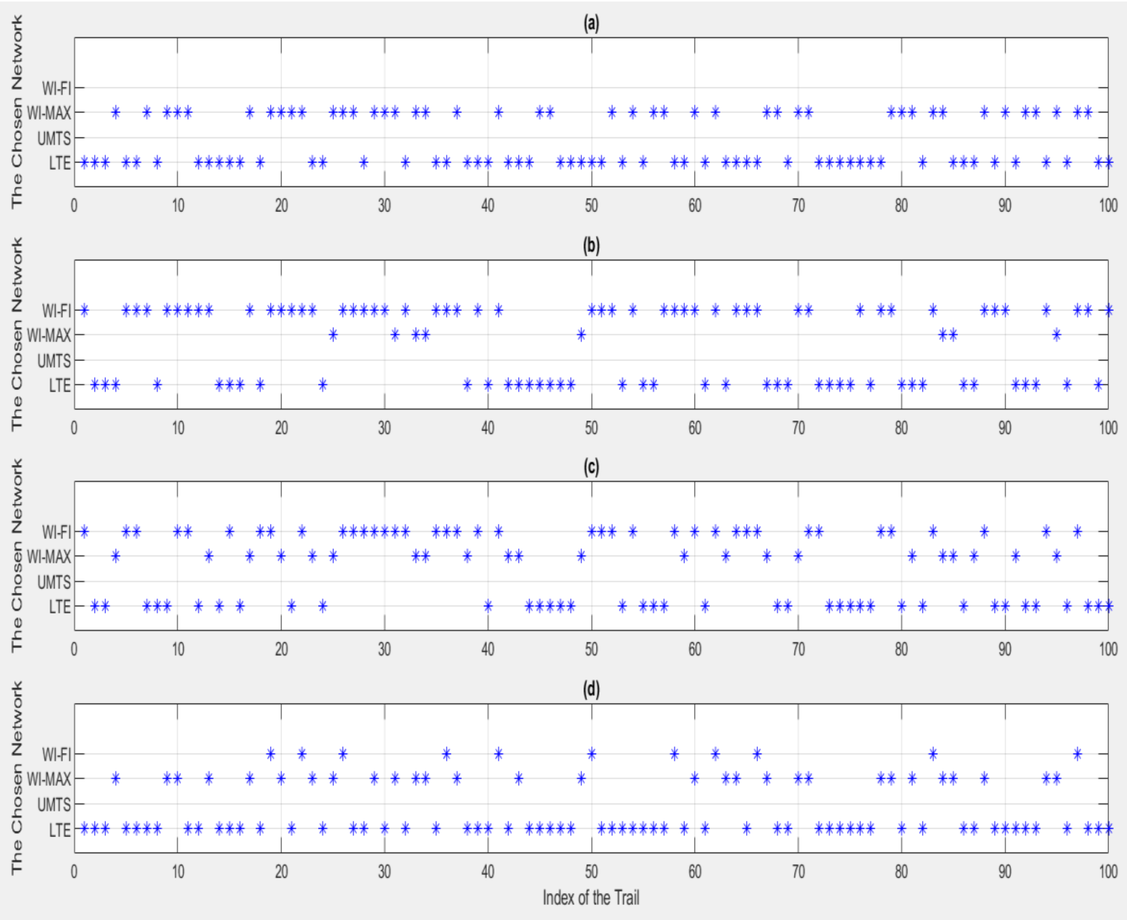

Figure 4.6: The selected networks of the first scenario for (a)TOPSIS, (b)GRA, (c)VIKOR, and (d)The proposed method.

Since the attributes of any network are set randomly in each trail, the execution of the scenario of 100 trails is repeated for 100 times and the average of each attribute was calculated. The following sub-sections show the result for each one of the attributes.

4.3.1. Vertical Handover of the First Scenario

Reducing vertical handover can enhance users' QoS in HWN. Figure 4.7 illustrates the values of handover for all of the techniques where the value is 49, 54, 62 and 49 for the TOPSIS, GRA, VIKOR, and the Proposed Method, respectively. The proposed method achieved a lower value for the handover than the other methods.

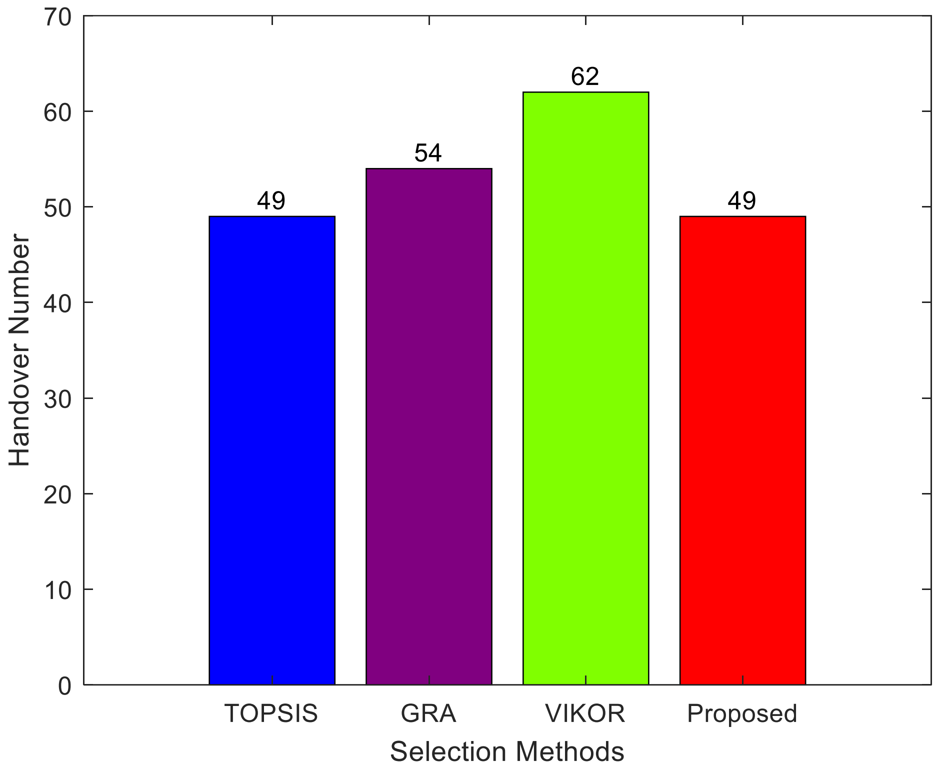

Figure 4.7: The Vertical handover of all Techniques for the first scenario.

4.3.2. Network Delay of the First Scenario

It is important to incorporate delay metrics into the algorithm's decision-making process to mitigate the impact of delays on network selection algorithms. Figure 4.8 shows the values of network delay for all techniques. The Average values of the delay of the TOPSIS, GRA, VIKOR, and the Proposed Method are 44.51, 79.38, 70.07, and 51.94 ms, respectively. Here, the value of the delay did not constitute the highest value, also not lowest value, so it was average among the rest of the method. The reason for the lies in this case, not in proximity or distance from the network, because the assumption here is that the user is fixed and not mobile, but rather it is caused by the large number of users who occupy an area of the network at this time.

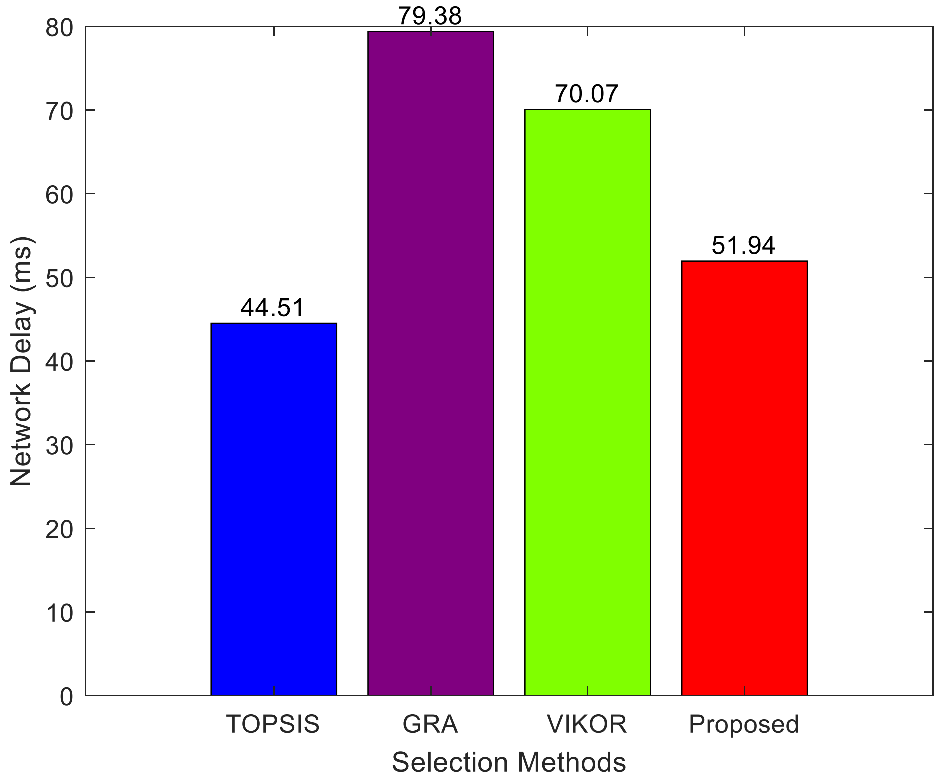

Figure 4.8: The Network delay of all Techniques for the first scenario.

4.3.3. Network Jitter of the First Scenario

The jitter metric in network selection algorithms is important for ensuring optimal network performance and minimizing the impact of packet delays on the overall user experience. Figure 4.9 is the average values of the jitter for TOPSIS, GRA, VIKOR, and the Proposed Method which are 6.74, 12.4, 11.73, and 9.03 ms, respectively that shows the proposed method has a jitter is higher than the TOPSIS but it is lower than the GRA and VIKOR methods.

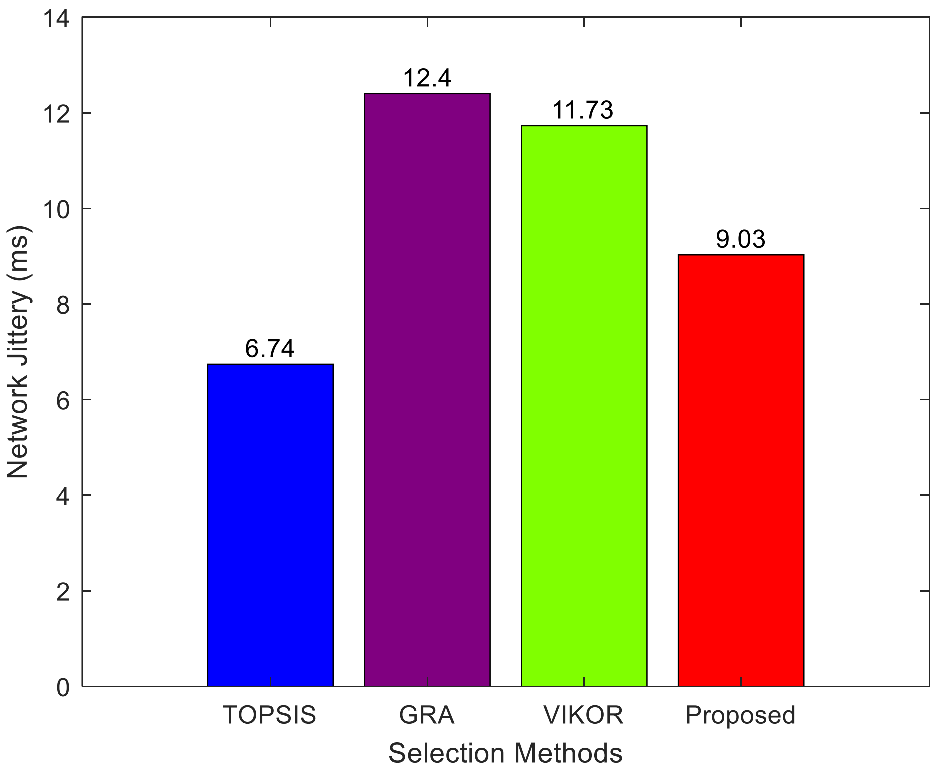

Figure 4.9: The Network Jitter of all techniques for the first scenario.

4.3.4. Packet loss-rate of the First Scenario

The packet loss rate result for network selection algorithms can provide valuable insights into the algorithm's performance. Figure 4.10 illustrates the values of packet loss rate for all techniques and it is for TOPSIS, GRA, VIKOR, and the Proposed Method are 2.46, 3.61, 3.11, and 2.57, respectively. Also, the proposed method obtains packet loss-rate lower than the GRA and VIKOR but higher than TOPSIS method.

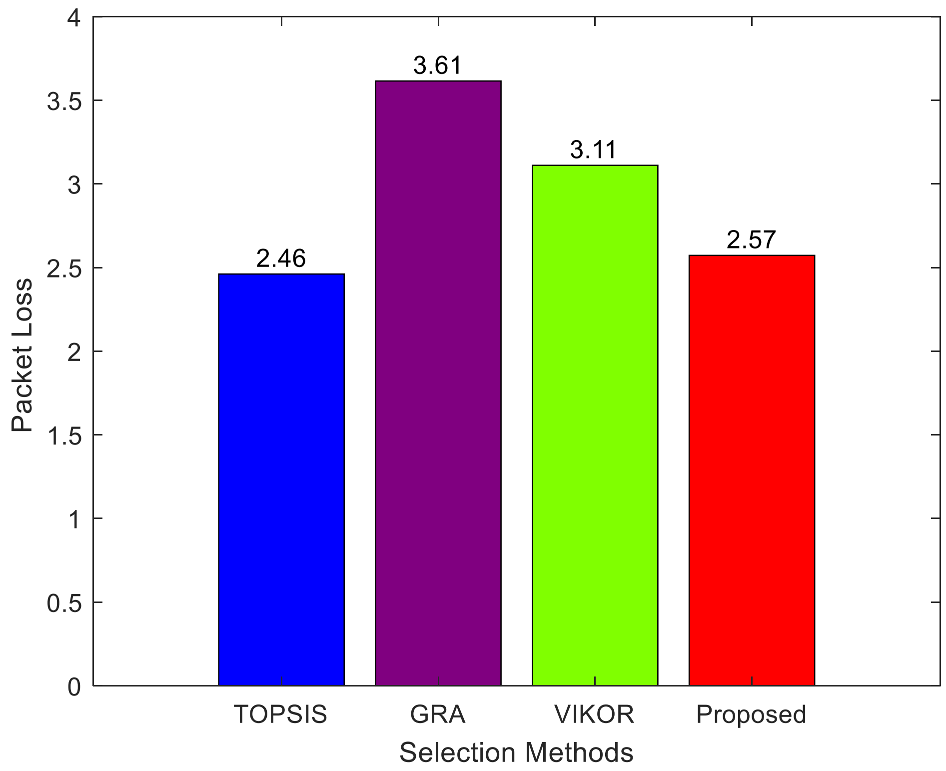

Figure 4.10: The Packet Loss Rate of all techniques for the first scenario.

4.3.5. Throughput of the First Scenario

The results of throughput for network selection algorithms can vary depending on many factors, such as the specific algorithm used, the network conditions, and the applications being used. The aim is to select the network that will provide the highest possible throughput for a given application or set of applications. As such, higher throughput generally means faster data transfer rates and better overall network performance. Figure 4.11 shows the average values of the throughput of the TOPSIS, GRA, VIKOR, and the Proposed Method which are 71.3, 52.09, 57.54 and 69.23 Mbps, respectively. It is clear that the proposed method achieved a high throughput as close as to TOPSIS method.

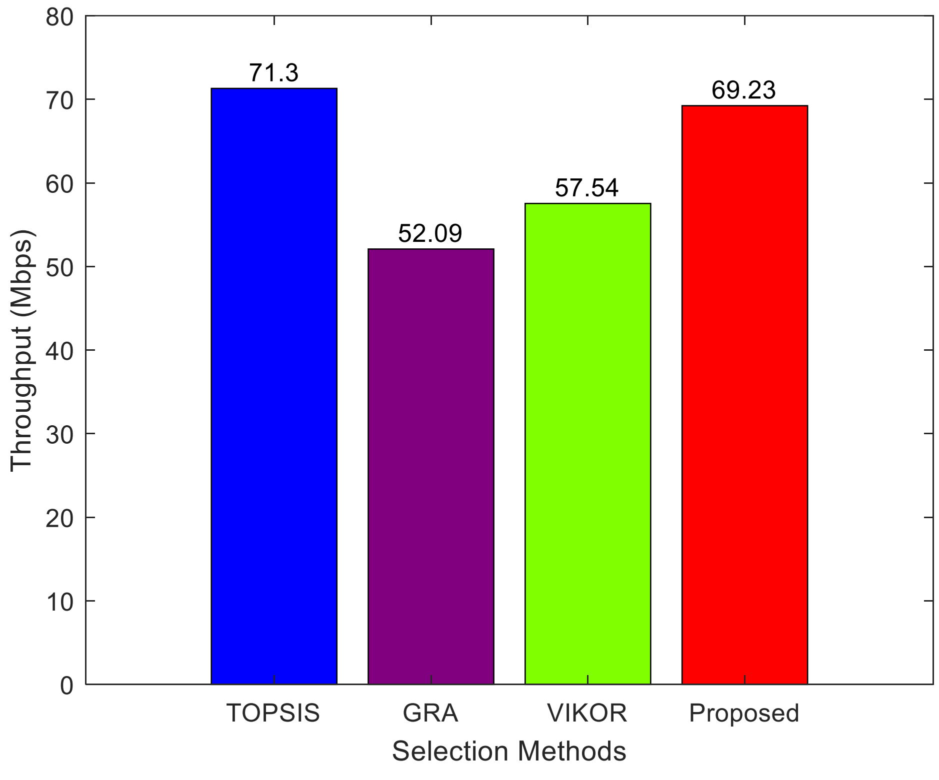

Figure 4.11: The Values of Throughput of all techniques for the first scenario.

4.3.6. The Cost of the First Scenario

The results of cost for network selection algorithms are an important performance metric that can help organizations make informed decisions about network selection based on the cost of using each available network. Figure 4.12 illustrates the average values of the cost of the TOPSIS, GRA, VIKOR, and the Proposed Method are 7.63, 4.4, 5.22, and 7.45, respectively. It did not achieve the best price, but it was lower than the TOPSIS.

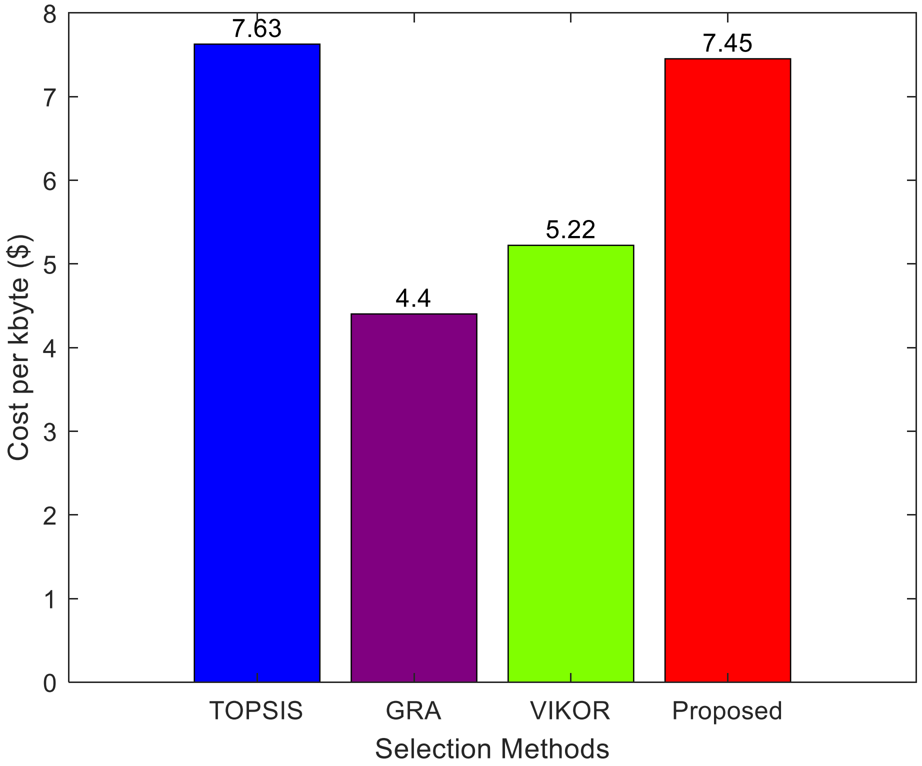

Figure 4.12: The values of the cost of all techniques for the first scenario.

4.3.7. The Effect of Execution Repetition Number

The implementation for the first case was repeated several times. Table 4.2 shows the Average rating for attributes of each method with 100 trails that repeated over 100 times and 200 times. The comparison between these two cases shows that the attributes values are extremely the same because of the application of the averaging over 100 trails and 100 times or 200 times which makes the results more stable.

Table 4.2: The Results of different Repetition Number for all techniques.

Repetition Number	**Attribute**	**TOPSIS**	**GRA**	**VIKOR**	**PROPOSED**
100	handover	49	54	62	49
	Delay	44.51	79.38	70.07	51.94
	Jitter	6.74	12.4	11.73	9.03
	Packet loss-rate	2.46	3.61	3.11	2.57
	throughput	71.3	52.09	57.54	69.23
	Cost	7.63	4.4	5.22	7.45
200	handover	49	54	62	50
	Delay	44.48	79.34	70.14	52.12
	Jitter	6.77	12.33	11.7	9.04
	Packet loss-rate	2.44	3.58	3.11	2.57
	throughput	71.25	52.55	57.7	69.31
	Cost	7.63	4.47	5.24	7.44

4.4. Mobile Node Scenario

The second approach in the MATLAB program, a simulation of mobile and wireless networks was applied and simulated, where the mobile phone is move from one region to another. The mobile moves within the heterogeneous wireless network environment and receives a signal from the networks, either all networks or one of them or two or others depending on the location of the mobile during its movement from one place to another. Four networks are used. Consider a mobile device that has four interfaces and can select from the LTE, UMTS, WiFi, and WiMAX access networks. In process of Vertical Handover decision within HWNs, the evaluation relies on several metrics, namely : delay, loss rate, jitter, throughput and cost. the various attribute values that are applied to each access network as in Table 4.1. Also, Table 4.3 presents the initialization values for each network.

Table 4.3: Simulation Networks Parameters.

Parameters	Values
LTE coverage range	1700 m
UMTS coverage range	1700 m
WIFI coverage range	200 m
WIMAX coverage range	6000 m
Area	8000x10000

Figure 4.13 illustrates the simulation environment of the route of the mobile node and the heterogeneous networks (Wi-MAX, LTE, UMTS, and Wi-Fi) .

The scenario starts by calculating the coverage range for each network based on Equation 2.24 where the red, yellow, green and blue circle represent the coverage area of the WIMAX, UMTS, LTE and WiFi networks, respectively. Then the mobile device starts moving according to a specific route of cyan color starting from location (10,10) with step 20 and finish at location (7000, 7000) which consists of 350 steps. At each step doing a checking of the distance between the device and each network based on Euclidean distance equation. If the measured distance is less than the coverage range of a network, then the mobile device can connect with it and this network will be taken under consideration during the network selection process. Otherwise, the network will be cancelled from the selection process.

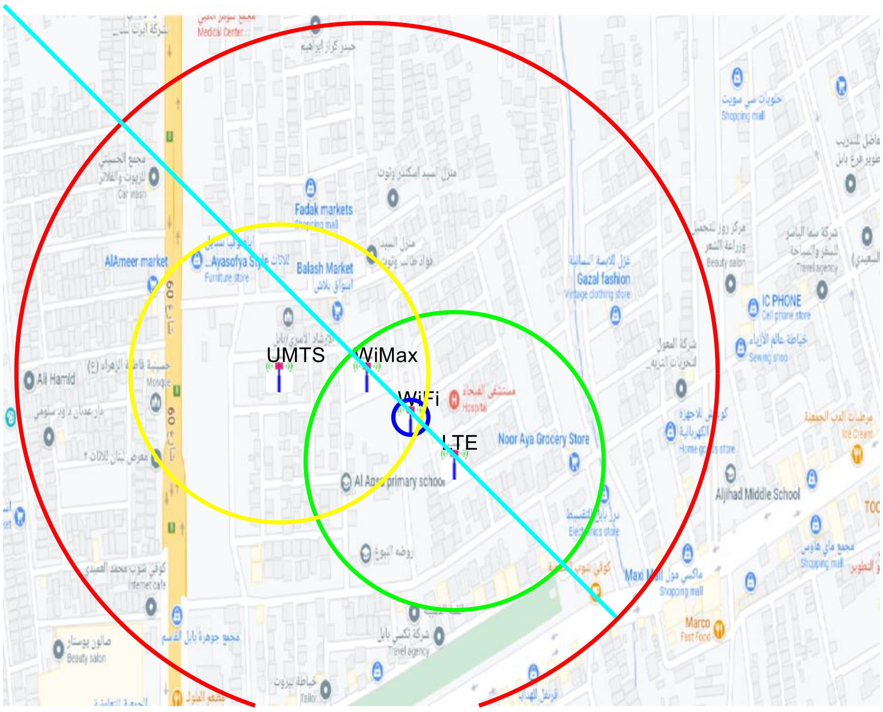

Figure 4.13: Simulation Environment of the Networks and mobile device Route.

Figure 4.14 demonstrates the network selection along the route for each technique. The results of the second scenario are presented in the following sub-sections.

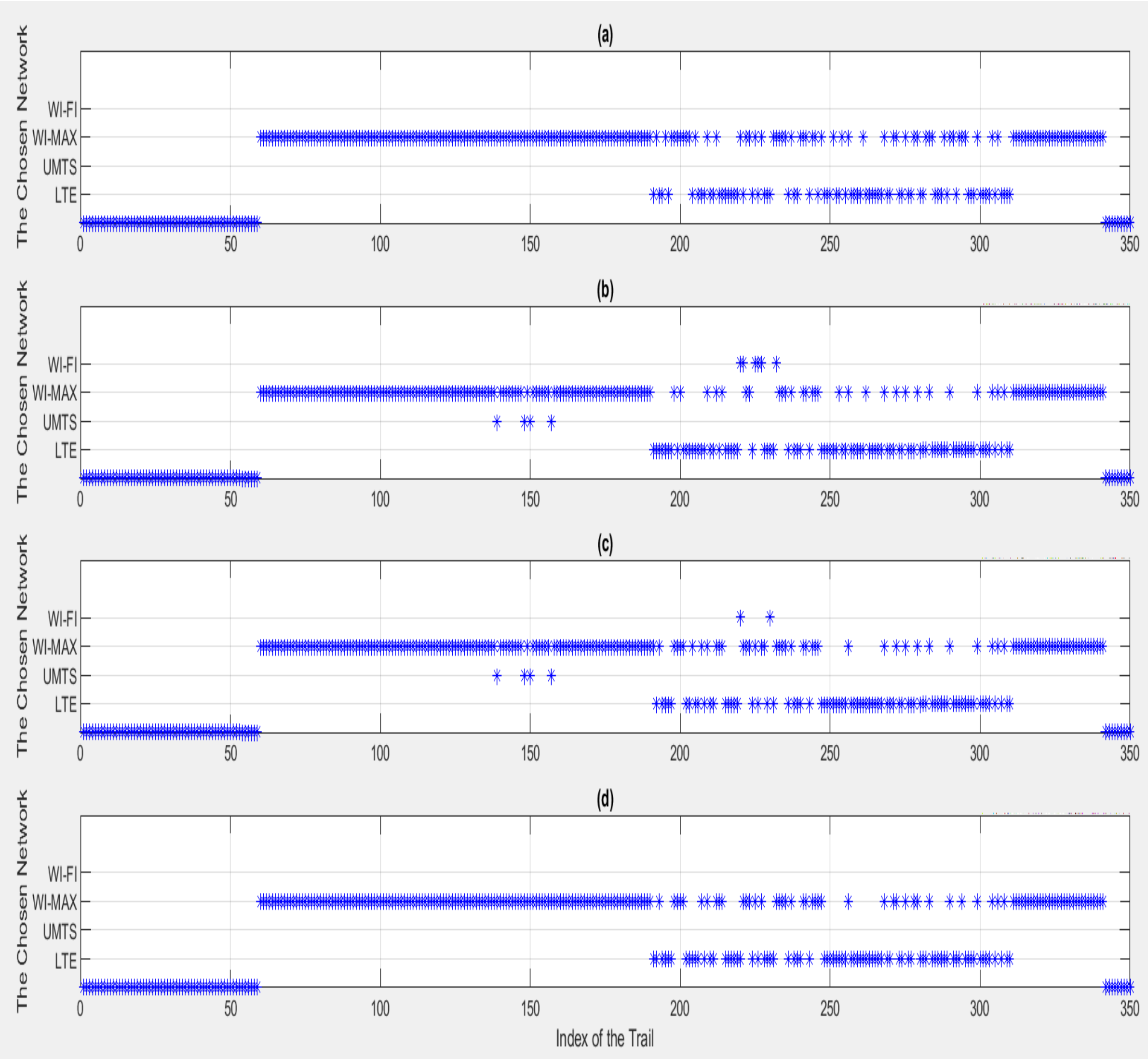

Figure 4.14: The selected networks of each technique for the second scenario (a)TOPSIS, (b)GRA, (c)VIKOR and (d) The proposed method.

4.4.1. The Vertical Handover of The Second Scenario

Figure 4.15 illustrates the values of the vertical handover in the second approach. The values of the handover are 64, 62, 63, and 52 for the TOPSIS, GRA, VIKOR, and the Proposed Method, respectively. Clearly, the proposed method obtains the lowest value where it decreases the handover by 19%, 16%, 17% in comparison to TOPSIS, GRA, VIKOR, respectively.

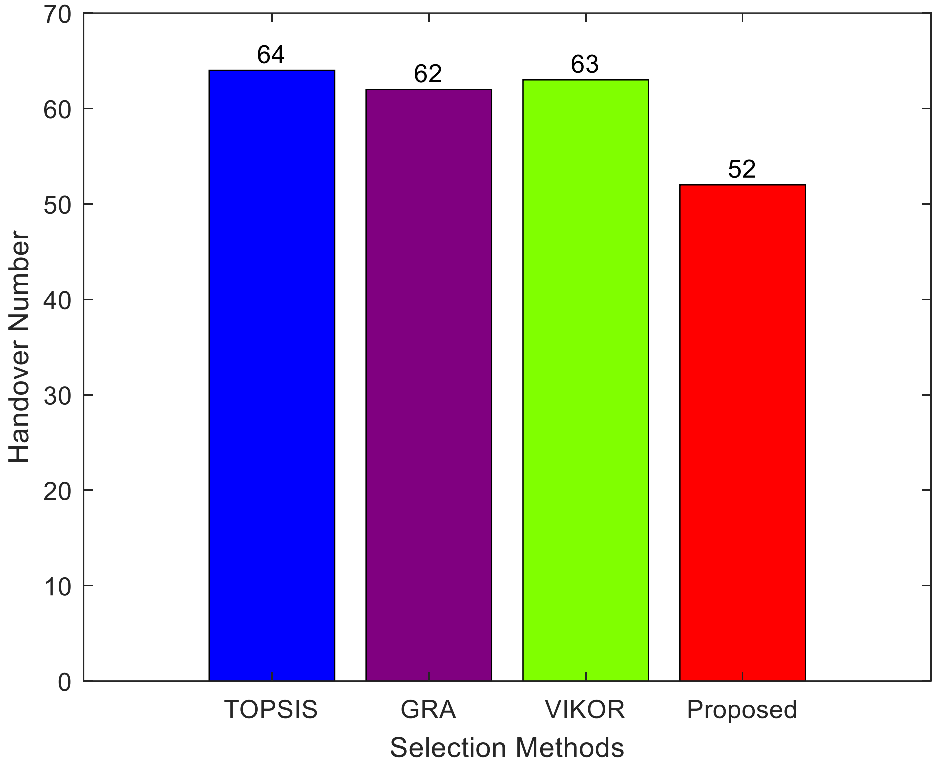

Figure 4.15: The Vertical handover for MADM methods and the Proposed Method of the second scenario.

4.4.2. Network Delay of The Second Scenario

In the second scenario, where the mobile moves between networks and measures the delay. To clarify, figure 4.16 shows the values obtained for each of the technologies: TOPSIS, GRA, VIKOR, and the proposed Method. The values are as follows, in sequence: 43.47. 46.68. 45.5. and 44.64.

In this case, the proposed method achieved a low delay not the best one but it was closely to the best result because the mobile moved from one place to another, and it might arrive in a place where it does not receive any network.

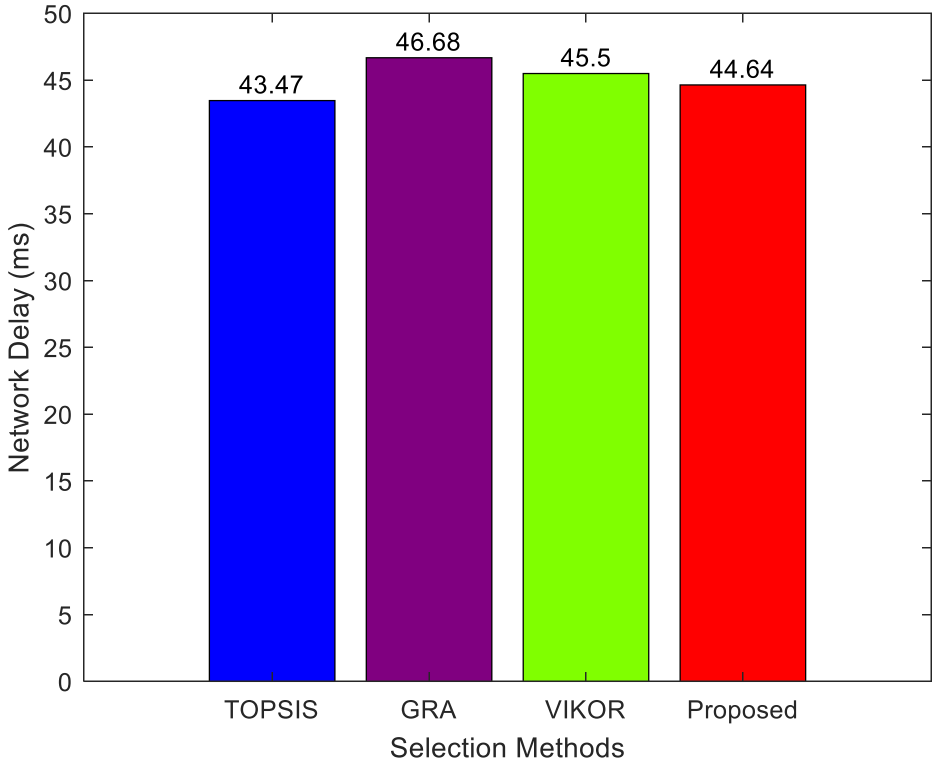

Figure 4.16: The Network delay of all Techniques for the second scenario.

4.4.3 Network Jitter of The Second Scenario

It should be noted the specific reasons and levels of jitter can differ depending on the network infrastructure, technology used, and overall network conditions. Effective network management and optimization techniques can help minimize jitter and ensure smoother data transmission. Figure 4.17 shows the values of jitter of the TOPSIS, GRA, VIKOR, and the Proposed Method, which are 6.36, 6.87, 6.8, and 6.62, respectively. Also, the proposed method is as close as possible to the lowest value.

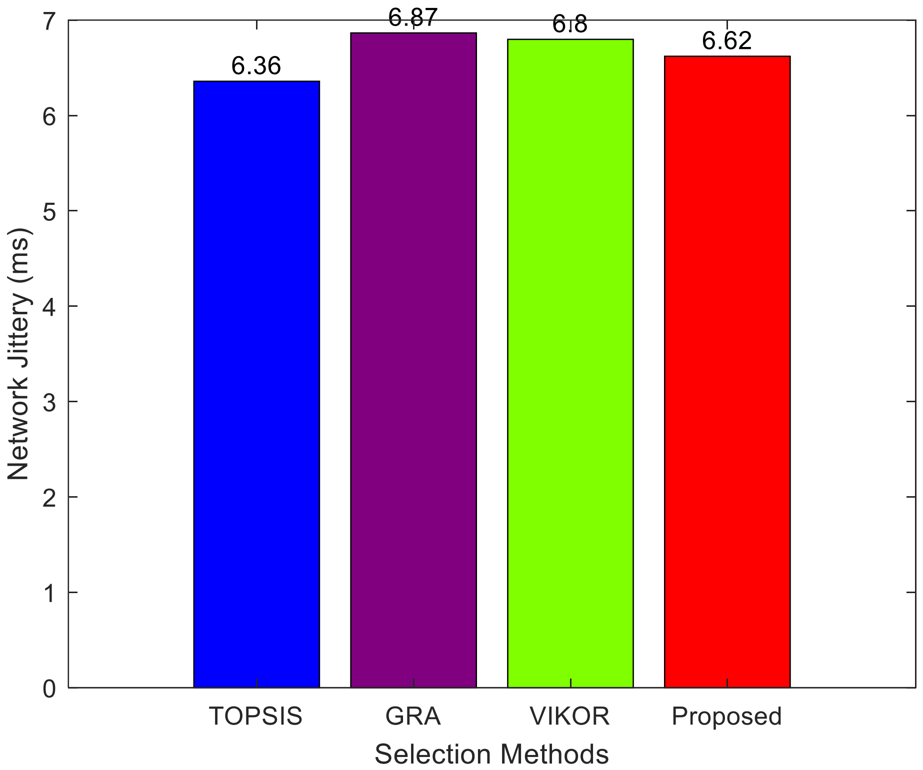

Figure 4.17: The Network Jitter of all techniques for the second scenario.

4.4.4 Packet Loss Rate of The Second Scenario

On specific techniques and strategies to reduce packet loss may vary depending on the network infrastructure, technology being used, and the specific causes of packet loss in a particular environment. Figure 4.18 shows values of the Packet Loss-Rate that are 2.73, 2.74, 2.72 and 2.7 for the TOPSIS, GRA, VIKOR, and the Proposed Method, respectively. Here, all methods obtain approximately the same values of the packet loss rate.

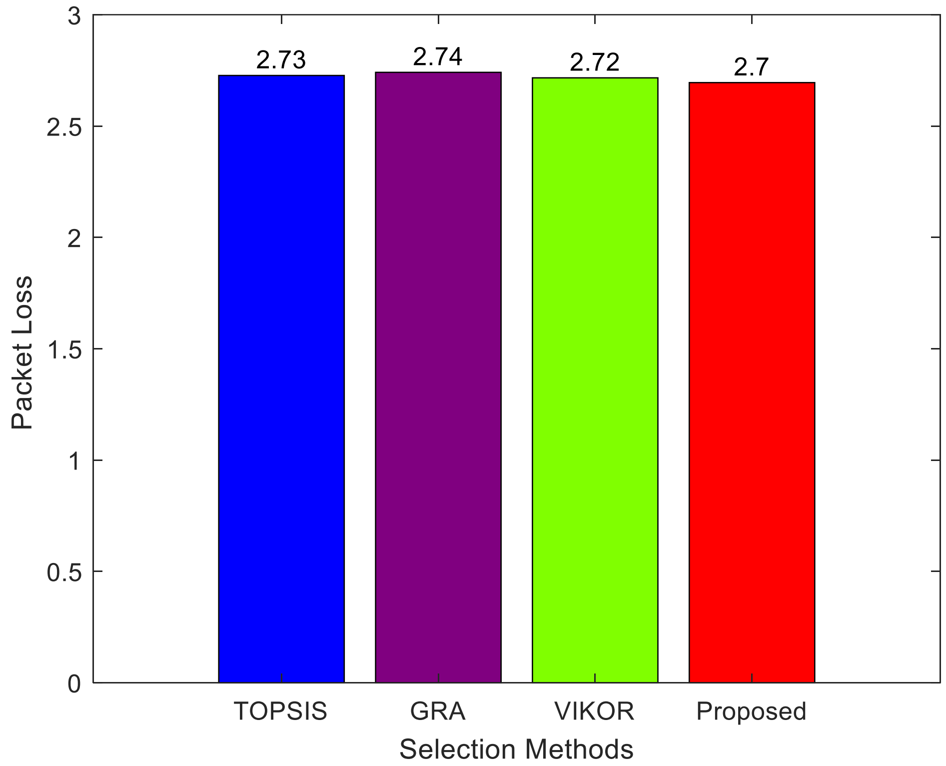

Figure 4.18: The Packet Loss Rate of all techniques for the second scenario.

4.4.5 The Throughput of The Second Scenario

The throughput affected by several reasons, including an increase in the delay, including congestion in the network, including the insufficient space of bandwidth. Figure 4.19 shows the result of throughput are 62.18, 60.56, 60.84 and 62.7 for the TOPSIS, GRA, VIKOR, and the developed method, respectively. It is clear that the proposed method achieved the highest throughput with little difference corresponding to TOPSIS and increasing ratio of 3.5% and 3% compared to GRA and VIKOR methods, respectively.

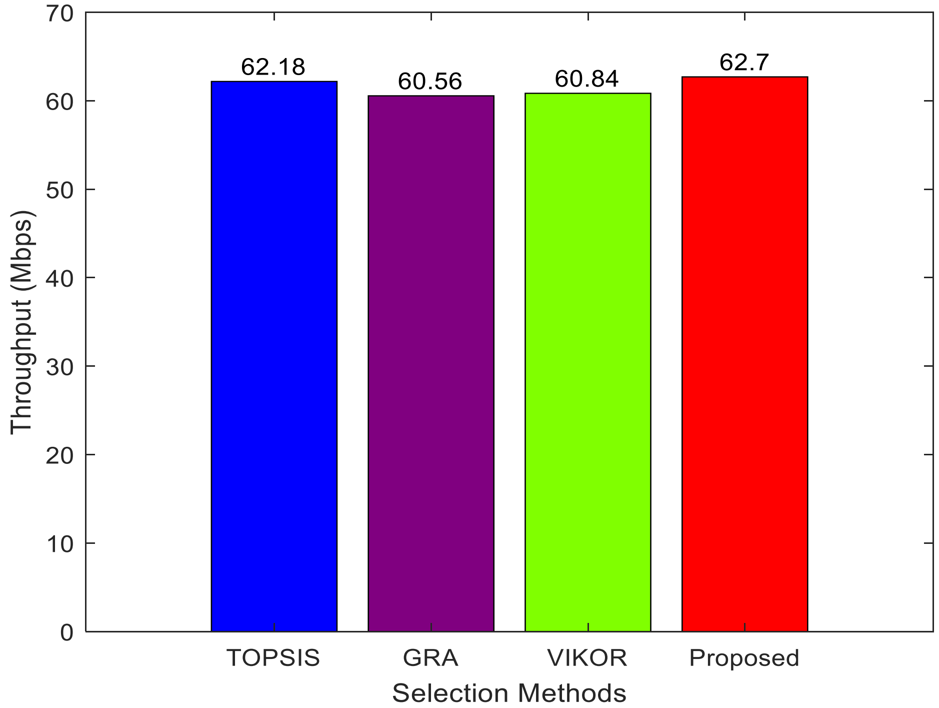

Figure 4.19: The Values of Throughput of all techniques for the second scenario.

4.4.6 The Cost of The Second Scenario

It should be noted that pricing models and cost factors can vary significantly across different service providers and geographic regions. Figure 4.20 presents the values of the cost of the TOPSIS, GRA, VIKOR, and the developed method which are 6.73, 6.76, 6.76 and 6.85 respectively. Obviously, all techniques provide very closely results.

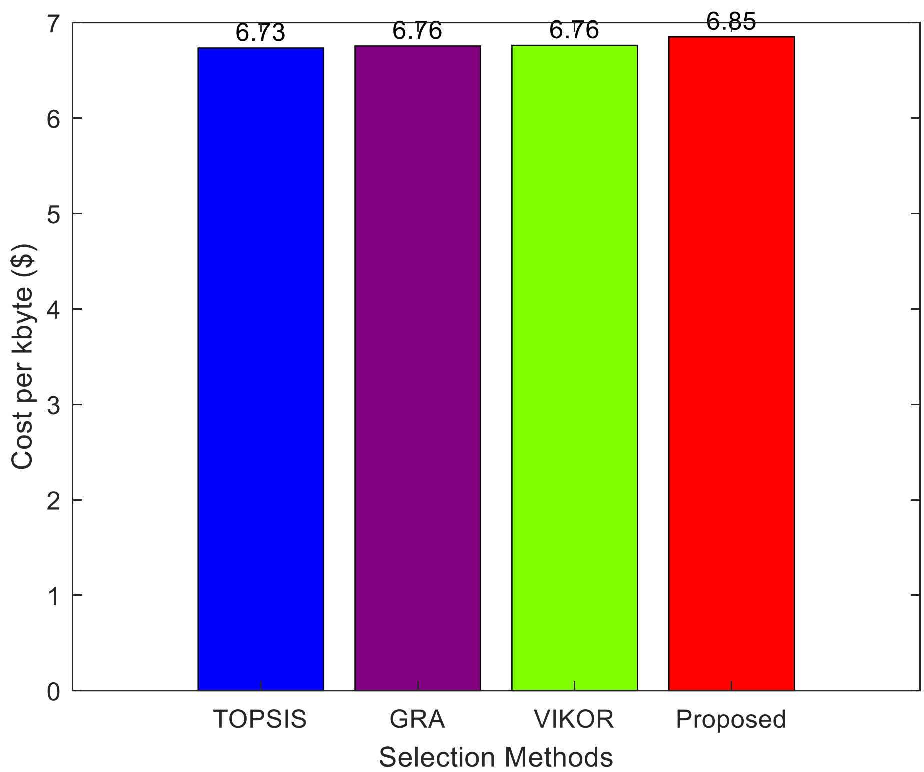

Figure 4.20: The values of the cost of all techniques for the second scenario.

4.5. Summary

In this chapter, the implementations of the TOPSIS, GRA, VIKOR and the proposed method were presented and the results of all techniques were discussed. Two scenarios were considered in the implementation. The first scenario is used fixed location of the node, and the second scenario is used mobile nodes (changing the location of the node). Six parameters represented by the handover, network delay, network jitter, packet loss rate, throughput and the cost, are used in the evaluation and comparison among these techniques. The first scenario is repeated different times to investigate the effect of repetition on the performance.

In all cases, the proposed method obtains very good performance by decreasing the number of handovers, delay, jitter, packet loss rate and the cost. Also, increasing the throughput of the network. On the other hand, the proposed method increased the reliability of network selection because of it depends on three different methods to get the decision rather than one method.

Chapter Five

Conclusions and Future Work

5.1 Conclusions

The selection of networks in heterogeneous wireless systems presents significant challenges. Its goal is to ensure smooth mobility across various radio-air interfaces. The following points can be concluded:

1- The Multiple Attribute Decision Making method offers an effective structure for ranking candidate networks in heterogeneous wireless environments based on their performance across multiple attributes.

2- This thesis introduces a developed technique for decision-making for handover in heterogeneous wireless networks. The proposed scheme combines the TOPSIS, GRA, and VIKOR methods to make the final decision. Each method individually ranks the networks, and their rankings are then aggregated through the Ensemble Average to select the optimal network.

3- Three methods of MADM represented by TOPSIS, GRA and VIKOR and the proposed method are implemented with two scenarios (fixed location and mobile location) of the node.

4- The performance evaluation of these methods primarily focuses on obtaining a highly reliable system as well as minimizing the number of handovers required. For fixed node scenario that obtains average vertical handover of 49, 54, 62 and 49 and for the mobile node scenario, the vertical handovers are 64, 62, 63 and 52 for the TOPSIS, GRA, VIKOR, and the proposed method, respectively. This outcome is advantageous as it ensures that users are connected to the best network, allowing them to maintain a stable connection for extended periods. Consequently, this promotes a seamless and reliable network experience for the users. But the time of selection process will increase in the proposed method because of it depends on execution of the three methods with the averaging.

5.2 Future Works

In the future, an alternative technique can be explored with the ensemble average to address the decision problem. Also, the voting system can be used with three or more methods to get the decision of network selection. Another potential avenue for future research is the development of a novel framework for mobility management, particularly focusing on network mobility handover scenarios.

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الخلاصة

في الجيل القادم من الشبكات اللاسلكية والمتنقلة غير المتجانسة، قد تتمكن المحطة المتنقلة المجهزة بواجهة متعددة من اختيار شبكة وصول مثالية في أي مكان وفي أي وقت. ويشار إلى التسليم السلس بين التقنيات المختلفة بالتسليم الرأسي (VHO). ومع ذلك، فإن التحدي الرئيسي هو توفير اتصال سلس بالمحطة المتنقلة في هذه البيئة غير المتجانسة. ولذلك، يحتاج VHO إلى عملية اختيار شبكة فعالة بناءً على معلمات الشبكة المتعددة.

تقدم هذه الأطروحة خوارزمية اختيار شبكة جديدة تعتمد على تقنيات MADM المتمثلة في تقنية ترتيب الأفضلية من خلال التشابه مع الحل المثالي (TOPSIS)، والتحليل العلائقي الرمادي (GRA)، وVIseKriterijumska Optimizacija I Kompromisno Resenje، (VIKOR) مع متوسط المجموعة إلى تصنيف الشبكات البديلة.

يتم استخدام العديد من المقاييس لتقييم النظام المتمثل في التسليم وتأخير الشبكة وارتعاش الشبكة ومعدل فقدان الحزمة والإنتاجية والتكلفة. تم تنفيذ الطريقة المقترحة ومحاكاتها في سيناريوهين: السيناريو الأول يعتبر موقع ثابت للعقدة مع ١٠٠ مسار عشوائي وتكرارها ١٠٠ مرة. بينما اعتمد السيناريو الثاني عقدة متحركة وفق مسار محدد بـ ٣٥٠ خطوة ومسارات اختيار. أظهرت نتائج المحاكاة لجميع السيناريوهات أن الطريقة المقترحة حصلت على أدنى قيمة لمتوسط التمرير الرأسي مقارنة بـ TOPSIS وGRA وVIKOR. كما تم تقليل تأخير الشبكة وارتعاشها بنسبة أقل من ٢٥٪ تقريبًا مقارنة بـ GRA وVIKOR لسيناريوهين. بالإضافة إلى أن الطريقة المقترحة أدت إلى زيادة الإنتاجية بحوالي ٢٪ وخفض معدل فقدان الحزمة بحوالي ١٠٪. بينما تم زيادة التكلفة في السيناريو الأول وأظهر السيناريو الثاني نفس التكلفة لجميع الطرق. وأخيرا، قدمت الطريقة المقترحة أداء جيدا من حيث مقاييس الشبكة والموثوقية ولكن تم زيادة تعقيد النظام.

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بابل
كلية تكنولوجيا المعلومات
قسم شبكات المعلومات

اختيار الشبكة اللاسلكية الهجينة بالاعتماد على MADM مع طريقة معدل المجموعة

رسالة مقدمة

إلى مجلس كلية تكنولوجيا المعلومات في جامعة بابل كجزء من متطلبات الحصول على درجة الماجستير في تكنولوجيا المعلومات / شبكات المعلومات

من قبل

فاطمة سمير حسن سلمان

بأشراف

م.د. راسم عزيز كاظم

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