Exponential Weighting based Network Ranking for Heterogeneous Wireless Networks

By

Faizan Bashir

00000275064

Supervisor

Dr. Mian Ilyas Ahmad

MASTER OF SCIENCE

in

Systems Engineering

School of Interdisciplinary Engineering & Science (SINES)
National University of Sciences and Technology (NUST)
Islamabad, Pakistan

June 2022

Exponential Weighting based Network Ranking for Heterogeneous Wireless Networks

By

Faizan Bashir

00000275064

Supervisor

Dr. Mian Ilyas Ahmad

A dissertation submitted to National University of Sciences & Technology in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE

in

Systems Engineering

School of Interdisciplinary Engineering & Science (SINES)

National University of Sciences and Technology (NUST)

Islamabad, Pakistan

June 2022

This thesis is dedicated to *my beloved family members*

and to my supervisor Dr. Mian Ilyas Ahmad

Declaration

I, Faizan Bashir declare that my MS thesis title

Exponent Weighting based Network Ranking for Heterogeneous Wireless Networks

is my own work and has not been submitted previously by me for taking any degree from this University "National University of Sciences and Technology (NUST), Pakistan" or anywhere else in the country/world.

At any time if my statement is found to be incorrect even after my Post Graduation, the university has the right to withdraw my MS degree.

Faizan Bashir,
00000275064

Copyright Notice

Acknowledgement

Do they not see the birds above them with wings outspread and [sometimes] folded in? None holds them [aloft] except the Most Merciful (Allah). Indeed, He is the Al-Seer of everything" (Al-Qur'an: Surah Al-Mulk – Verse 19).

Claiming that the verse holds immense importance in my heart and has been one true source of motivation throughout this journey, would be an understatement. All praises to Allah the Almighty, who enlightened my mind and put me through numerous shades of experiences that instilled in me the strength and persistence I needed to successfully complete my research. In all honesty, I'd like to express the greatest of respects for Holy Prophet Muhammad (PBUH), the genuine beacon of knowledge.

I pay my earnest gratitude to my research supervisor **Dr. Mian Ilyas Ahamd** for his sincere guidance and encouragement. Apart from supervising, he inculcated in me the appetite for hard work and self-dependence. In addition, my GEC members: **Dr. Shehzad Rasool**, **Dr. Tariq Saeed** and **Engr. Fawad Khan**, must be acknowledged for their valuable advices and support throughout.

I also pay my heartiest gratitude to Mr. Muhammad Nawaz and Mr. Malik Abdul Saboor for their guidance and motivation. Special thanks to my closest friends and SINES fellows, Hassan bin Tariq, Salman Mushahid, Sulaiman Khan and Rana Umair Ahmad for their support and help to pass every hurdle. I am really grateful to my lab fellows, Mehboob Ul Rasool, Umer Shahid, Ahmad Hassan and Husnain Ahmad, for endless guidance and teachings, not only in the field of research but also for long lasting daily life.

It is worth mentioning my invaluable earning in the form of dearest friends during this period. Special thanks to Muzammal Janjua, Asif Duggal, Muhammad Usman Ramay, Imran Munir, Hamza Iftikhar, Ahsan Nawaz, Ali Gill, and Ali Raza for cheering me up every time the stress took a toll on me.

Finally, I am highly indebted to my parents, siblings and other family members for their unflagging love and unconditional support throughout my life. Thanks, and appreciations are extended to all who, directly or indirectly, lent their helping hands in this endeavor.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREIVATIONS

WLAN	Wireless Local Area Network
UMTS	Universal Mobile Telecommunications Service
HSPA	High Speed Packet Access
LTE	Long-Term Evolution
LAN	Local Area Network
Wi-Fi	Wireless Fidelity
IEEE	Institute of Electrical and Electronics Engineers
RSS	Received Signal Strength
SNR	Signal-to-noise ratio
HWN’s	Heterogenous Wireless Networks
MADM	Multiple Attribute Decision Making
SAW	Simple Additive Weighting
MEW	Multiplicative Exponent Weighting
AHP	Analytical Hierarchy Process
TOPSIS	Techniques for Order Preference by Similarity to Ideal Solution
GRA	Grey Relational Analysis
QoS	Quality of Service
RAT	Radio Access Technologies
SIM	Subscriber Identity Module
3G	3rd Generation
4G	4th Generation
5G	5th Generation
IP	Internet Protocol

ABSTRACT

Heterogeneous wireless networks (HWNs) provide communication related services in some specific region using multiple wireless access networks so that the users can access the networks with better quality of service (QoS). Typical component level access networks include wireless local area networks (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), 2G, 3G and 4G networks. This means that when a user terminal moves in HWNs environment, it experiences different available networks that must be ranked according to some criteria before deciding which network is suitable for the user terminal. This also relates to the activity/business of the user terminals for which they require the access of network, that is streaming, conversation, interactive and background use. The problem of ranking and selecting the best suitable network among multiple access networks according to some criteria that fulfils the user requirements and network performance attributes is an active research area in HWNs. Multiple network selection algorithms, including analytical hierarchy process (AHP), technique for order preference by similarity to ideal solution (TOPSIS), utility theory, multiplicative exponent weighting (MEW), and simple additive weighting (SAW) have been developed to handle this challenge. Their applications in some cases include the network performance attributes, while others involve user preference without using inherited network attributes. Therefore, the network selection algorithms are often integrated to cover both the user preferences and the network performance attributes. In this thesis, we utilized the AHP and TOPSIS algorithm and integrated their associated weights through multiplicative exponential weighting (MEW) approach. This allows us to cover both the user preferences and the network attributes in the network selection process. The AHP method identify a weighting criterion for the user preference and TOPSIS select weights based on current network attributes. The integration of the two classes of weighting criteria can be given equal or any other weightage in network ranking. The proposed approach of utilizing multiplicative exponent weighting in the use of network selection is compared with the existing multiplicative weighting by considering three predefined scenarios. It is observed that the proposed method shows better, or equivalent results as compared to the existing approach in all the three scenarios.

CHAPTER 1

INTRODUCTION

1.1 Heterogenous Wireless Networks

Wireless networks that use different radio access technologies are known as heterogeneous wireless networks. Heterogeneous wireless networks (HWNs) combine cellular networks, wireless LANs, and ad hoc networks with the Internet to enable flexible and diverse wireless network access (e.g., cellular, IEEE 802.11). For instance, a wireless network provides communication service through a local area network (LAN) and can sustain that service while switching to a cellular network is called a wireless heterogeneous network.

1.1.1 Radio Access Technologies (RAT's)

Radio access technologies have significantly evolved in recent years. A wide range of wireless signal coverage has been provided by the evolution of the cellular networks from GSM to UMTS to LTE. A range of WLAN standards (e.g., IEEE 802.11a, IEEE 802.11b, IEEE 802.11n, IEEE 802.11ac, etc.). and WiMAX also provide the user high-speed data transmission [1].

Global System for Mobile Telecommunications (GSM)

Global System for Mobile Telecommunications (GSM) was first specified by ETSI in 1990 as the most prevalent wireless access technology (European Telecommunications Standards Institute). It was originally intended for usage in Europe, but it is now used all over the world. Replacing analog systems of the first generation (1G). As a wireless access technology, GSM is sometimes referred to as a second-generation (2G) technology. The radio interface of GSM makes use of TDMA (Time Division Multiple

Access) technologies to distribute a single frequency across several users simultaneously. Each user is given a time slot in a sequence that all share a common frequency[2].

The Subscriber Identity Module (SIM) is a detachable smart card that contains the user's subscription details and phone book. This functionality makes it simple for consumers to transition between devices. As a result of roaming agreements between GSM operators, end-users can use their mobile devices in other countries.

Universal Mobile Telecommunications Systems (UMTS)

Universal Mobile Telecommunications Systems (UMTS) is the most important third-generation (3G) mobile telephony system, as defined by the 3GPP in its first version (Third Generation Partnership Project). It provides the packet-switched data transmission of voice, video, and text with a speed of 2Mbps. No matter where you are in the globe, UMTS provides the same set of services to mobile computer and phone customers. Based on the GSM communication standard, UMTS is an evolution of UMTS. Major standards groups and manufacturers also support it as the standard for mobile consumers worldwide. It is expected that after UMTS is completely implemented, PC and mobile phone users would have the same set of capabilities regardless of where in the world they are. Using a combination of terrestrial wireless and satellite transmissions, users will be able to connect [3].

Long Term Evolution (LTE)

Fourth generation (4G) wireless technology, Long Term Evolution (LTE), delivers greater network capacity and speed for mobile devices compared to 3G technology. In comparison to 3G, LTE enables peak data transmission speeds of up to 100 Mbps downstream and 30 Mbps upstream, which is significantly faster than 3G. It offers reduced latency, expandable bandwidth capacity, and backward compatibility with the existing GSM and UMTS technology. An increase in peak throughput on the order of 300 Mbps was achieved by LTE-Advanced (LTE-A)[4].

Wireless Local Area Network (WLAN)

In a wireless local area network (WLAN), a group of collocated computers or other devices build a network using radio emissions rather than a wired connection. This allows users to roam about the area and stay connected to the internet. In addition to connecting to the Internet, a WLAN can also be used to connect to other networks. IEEE 802.11-based wireless LANs are the most commonly utilized computer networks in the world. The Wi-Fi Alliance owns the trademark rights to the term "Wi-Fi" which has become widely used. They are used for home and small office networks that connect laptop computers, printers, smartphones, Web TVs, and gaming devices to a wireless router that connects them to the internet. Hotspots at restaurants, coffee shops, hotels, libraries, and airports allow customers to connect to the internet using portable wireless devices[5].

WiMAX

WiMAX stands for worldwide interoperability for microwave access. It’s the technology that provides broadband communication services over a wide area with a high-speed data rate. Its communication technology is based on IEEE 802.16 standard and use the technology of point to multipoint networking. Using WiMAX technology, a wide range of users can benefit from high-speed data networks, including those in developed countries who want to avoid the expense and time of setting up a wired network, as well as those in rural areas who need fast access but cannot use wired solutions because of the distances and costs involved - effectively providing WiMAX broadband. Mobile applications are also taking advantage of the high-speed data it provides [6].

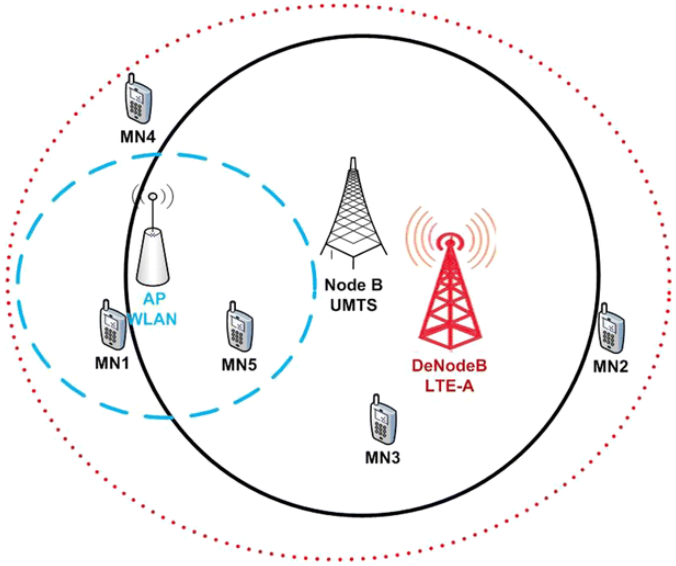

Figure 1.1: Heterogenous Wireless Network: A network of mix of UMTS, LTE and WLAN

1.1.2 Network Selection

Due to the wide variety of user services and differences in wireless network's data transmission quality, it is mandatory to be connected with a suitable network that provides the users with appropriate data transmission service and make sure a stable connection service. Therefore, network selection has become a hot topic in research for heterogeneous wireless network environments [3], [4]. In a single wireless network environment, decision attributes of the network are mostly related to the wireless link quality characteristics such as receive signal strength (RSS), signal to noise ratio (SNR), or the signal to interference plus noise ratio (SINR) [5]. Usually, there is only one decision attribute used for network selection in a single wireless network environment. The main goal of a single network coverage area is just to maintain the physical connection with the wireless channel. On the contrary, in heterogeneous wireless networks (HWN's) environments, users can access multiple networks with their different network parameters quality, a wide range of service types, and user preference. Therefore, the selection of wireless network must not be based on certain network decision attributes, but it should be comprehensively based on multiple network attributes such as receive signal strength (RSS), bandwidth, delay, jitter, network load, packet loss, and energy consumption that will allow the users to access optimal and most suitable network according to the user business requirements [6]. A scenario is mentioned in figure 1 in which a mobile user moves from one place to another and faces a heterogeneous wireless network environment having multiple available networks with diverse signal coverage and decision attributes such as bandwidth, delay, packet loss, jitter, and cost. Though every user has a diverse range of business requirements such as voice, video, and data, so user terminal decides which network is suitable to address the user's personal/ business requirements. The user terminal decides the suitable network based on the basic network decision attributes and user preference by using the MADM algorithms. This study intended to improve the selection mechanism and make sure seamless communication for users [1].

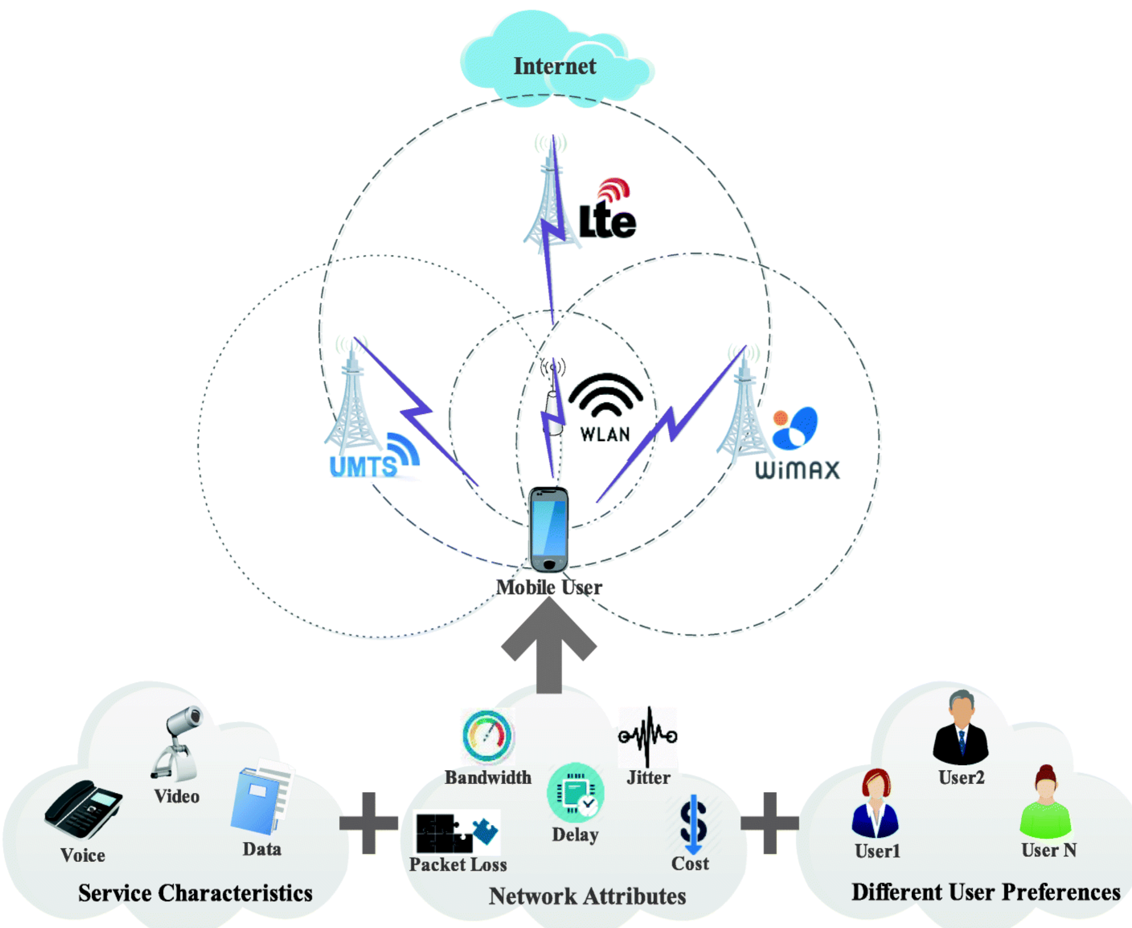

Figure 1.2: Scenario with HWNs for network selection

1.2 Problem Statement

The multiple radio access technologies such as GSM, UMTS, LTE, Wi-Fi, and WiMAX are providing services to the users for different business requirements such as streaming, interactive, background, and conversational. The GSM standard specifies how 2G (second generation) networks operate. It provides a data speed of 64kbps and bandwidth from 30khz to 200khz with the use of digital signals. The UMTS standard specifies how 3G (third-generation) networks operate. It provides data speed up to 2Mbps and operates at the range of 2100Mhz with large broadband capabilities. The LTE standard specifies how a 4G (fourth generation) network operates. It provides data speed up to 20Mbps and delivers fast communication with a secure internet connection. Wi-Fi (wireless fidelity) provides a high-speed internet connection with a speed of 54Mbps and a 100m coverage range. WiMAX handles a large operable network with a speed of 70Mbps and a 90km coverage range [7].

The most challenging thing in these radio access technologies is the ranking of candidates' networks in heterogeneous wireless networks. When a user terminal moves in heterogeneous wireless environments then it faces multiple candidates' network then it is difficult to decide which candidate network is best suitable for the user terminal according to his business requirements such as conversation, interactive, background, and streaming [8]. To address this problem, multiple network selection algorithms such as AHP, TOPSIS, Utility Theory, MEW, and SAW are used that allow the user terminal to rank and select the best suitable network dynamically. But these algorithms have some drawbacks while executing the network selection, some algorithm does not rank the networks appropriately according to the quality of decision attributes some only consider the user preference and does not consider the predefined characteristics of network attributes. Some literature addresses this problem by using these algorithms in a combined way but sometimes it still does not rank the network appropriately in some cases.

Here we will address this problem by improving the ranking mechanism and address the network selection problem by making the combination algorithms as discussed above and that combination is not used before. We will use the analytical hierarchy process (AHP), a technique for order preference by similarity to ideal solution (TOPSIS) with the combination of multiplicative exponent weighting (MEW).

1.3 Motivation

Multi-Criteria Decision-Making (MCDM) refers to approaches for making decisions where multiple criteria (or objectives) considered simultaneously in order to rank or select appropriate solution amongst alternatives. Therefore, it can apply in any sort problems which involves multiple criteria's, alternatives and decision making of final solution. MCDM approaches have been used in a variety of fields according to many detailed researches which are given below.

- Supply chain management [9]
- Material selection for product design [10]
- Construction and project management specially in land selection [11]
- Operation research and soft computing [12]
- Energy, environment and sustainability field [13]
- Tourism management [14]
- Manufacturing systems [15]

Since our problem "network ranking in heterogenous wireless network" also involves multiple criteria's and alternatives so it can address with MCDM approaches as it is less complex and less computational time. This was the main motivation behind the selection of this problem if MCDM can provide the appropriate results in above mentioned fields then it can also perform well in ranking of networks within heterogenous wireless network environment.

1.4 Objectives

Following are some of our research objectives.

- Implementing and analyzing some of the existing algorithm from the literature for access network selection in heterogeneous wireless networks (HWNs).
- Designing of framework with the combination of AHP and TOPSIS algorithms with multiplicative exponent weighting.
- Implementation of designed framework on predefine scenarios in heterogenous wireless networks.

1.5 Thesis Organization

The thesis is organized in the following way: Chapter 2 consists of a literature review related review of our research in which we discussed different network selection algorithms such as multicriteria decision-making algorithms (MCDM), analytical hierarchy process (AHP), a technique for order preference by similarity to ideal solution (TOPSIS), utility theory, simple addition weighting (SAW), multiplicative exponent weighting (MEW) and combination of these algorithms. Chapter 3 comprises our used research methodology with a different combination of different network selection algorithms. Chapter 4 includes the results and discussion regarding our implemented methodology with the improved candidate improved network ranking. Finally, chapter 5 concludes the research with the future direction of our research.

CHAPTER 2

LITERATURE REVIEW

This chapter provides the background information of different techniques and algorithms used to address the network selection problem in heterogenous wireless networks environment as discussed in chapter 1.

2.1 Network Selection Techniques

Several different algorithms and techniques have been used in literature for selection of network in heterogenous wireless network but some of the most prominent techniques are given below.

1. Utility theory-based network selection[16]
    a. Single Criterion Utility Function
    b. Multi-criterion Utility Function
2. Multicriteria Decision making (MCDM) Algorithms[17]
    a. Simple Additive Weighting (SAW)
    b. Multiplicative Exponent Weighting (MEW)
    c. Analytical Hierarchy process (AHP)
    d. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)
    e. Gray Relational Analysis (GRA)

Each algorithm and techniques have its drawbacks while executing the ranking of networks' heterogeneous wireless network environment. Before going into details of techniques and algorithms, we will discuss decision attributes of different networks used in the heterogeneous wireless network environment and switching of one network to another network through handover process. Section 2.2 to 2.3 provides the background information on radio access technologies (RAT) and the handover process in switching from one network to another network respectively.

2.2 Utility theory

In contrast to the original concept of utility, network selection in HWNs defines utility as the degree of user or application satisfaction with the network's services. Although every user has a variety of user requirements and business requirements, so the degree of satisfaction also varied with the same network attribute value. Therefore, user satisfaction for each network decision attribute is measured by applying the utility functions to calculate the utility values [18]. The utility function value is a relative index value. In general, the utility value of a user's most satisfied attribute value is 1, whereas the utility value of the user's least pleased attribute value is 0 [19]. The bigger the parameter value for desirable criteria (e.g., bandwidth), the higher the degree of satisfaction; hence, the utility value is u(x). The bigger the parameter value for undesirable criteria (e.g., latency, jitter, packet loss ratio, price, and energy consumption), the lower the degree of pleasure; consequently, the utility value will be 1-u(x).There are different utility functions have been used in literature such as single criterion aggregate utility functions (linear, logarithm, exponential, sigmoid) and multi-criteria aggregate utility functions (additive, multiplicative exponential).

In [20], Goyal et al used single criterion utility functions such as linear, logarithm, exponential, and sigmoid functions for determining the utility value of each decision attribute of a network and comparing the results of each utility function for network selection problems in heterogeneous wireless network co-existing environment. The results show that the sigmoid function provides a better value in the ranking and selection of networks and considers the most suitable function in the network selection domain.

In [21], Shoaib et al address the network selection problem by using both single criterion utility functions and multi-criterion utility functions. They used the single criterion utility function to calculate the utility value of each network attribute and the multi-criteria utility function to calculate the overall utility value of a network. They optimized the ranking and network selection mechanism by using the sigmoid function and exponential utility function.

Issues

Based on above references, Ahmad et al. discussed the some of the drawbacks in [22] listed below.

- Required multiple utility functions for each mobile terminal, network criterion, and candidate alternative networks.
- Difficult to apply in heterogeneous wireless network co-existing environment as the mobile terminals scale up.
- The very restrictive assumption on user preferences. This restrictive assumption makes the utility-based network selection model simple but inaccurate.
- Less restrictive assumption makes the utility-based network selection model more accurate but more complicated.

2.3 Multicriteria Decision Making (MCDM)

Introduction

Multi-Criteria Decision Analysis, often known as MCDA, is a helpful tool that may be applied to a wide range of complicated decision situations. It is especially useful when dealing with challenges that are defined by a decision between two or more alternatives. It possesses all of the features of a valuable decision-support tool, including it assists us in concentrating on the most important things, is logical and consistent, and is simple to apply. At its core, MCDA is useful for the following tasks:

- By breaking down a complex decision into smaller, more understandable components
- Taking each component apart
- Bringing all of the pieces together to create a meaningful solution

When used in group decision-making, MCDA assists groups in discussing their choice opportunity (the problem to be solved) in a way that allows them to take into account the values that each individual believes are significant. It also provides a unique opportunity for people to think about and discuss intricate trade-offs between alternative options. In practice, it assists people in thinking, re-thinking, querying, adjusting, deciding, rethinking some more, testing, adjusting, and ultimately deciding [23].

The following are the five components of MCDA problems:

1. The purpose of the project

2. Group of decision-makers with differing points of view (preferences)
3. Alternatives to making a decision
4. Criteria for evaluation (interests)
5. Consequences or outcomes associated with a particular alternative/interest combination

2.3.1 MCDM in Network Selection

Multiple criteria decision making (MCDM) aims to select the most satisfactory choice from a range of alternatives by using attributes that quantify the performance of each alternative to arrive at the best possible decision. The choice is influenced by a variety of performance characteristics or factors, and alternatives are described by some attributes with a specific degree of attainment. For example, a car's purchase price, gas mileage, horsepower, brake system performance, etc., are all factors to consider while making a purchasing decision. In most MADM problems, the goal isn't explicitly stated; rather, it's left vague. Sometimes, it's stated as the purpose to maximize one's satisfaction. The limitations for MADM methods have previously been included in attributes.

In the selection of the best suitable network challenge, a candidate network is predetermined, and it is distinguished by its bandwidth, delay, packet loss, jitter, and so on, which are referred to as attributes in MADM. There are undoubtedly an endless number of possible networks, and the choice space is discrete. For instance, if we have four candidate networks A, B, C, and D, we will have just four choices for any attribute, such as bandwidth, delay, packet loss, jitter offered by networks A, B, C, and D, and so the decision space for data rate will be composed of these four discrete values. In a MADM technique, the decision matrix is divided into four sections: (a) alternatives, (b) attributes, (c) weights, and (d) measurements of alternative performance of the attributes. In the network selecting problem, different candidate networks represent distinct alternatives, performance attributes represent the factors influencing the decision (i.e., bandwidth, cost, delay, jitter, etc.), weights represent the relative importance of attributes, and performance measures represent quantitative indicators of how well (or poorly) an alternative meets the performance attributes.

2.3.2 MCDM Techniques

Some classical methods are developed in response to the nature of MCDM, including the weighted sum method (WSM), the weighted product method (WPM), the analytic hierarchy process (AHP), the elimination et Choix traduisant la réalité (elimination and choice expressing reality) (ELECTRE), the technique for order preference by similarity to ideal solution (TOPSIS), utility theory and others. However, the common assumption in most MCDM approaches is that all of the criteria are independent, which may not be the case in our network selection situation. Currently, according to our information, network delay, packet loss, bandwidth, and some other factors that we must consider are all highly correlated with one another in our network selection problem. In these MCDM techniques, our focus will be on AHP, TOPSIS, and the multiplicative exponent weighting (MEW) algorithm. Their detailed description and their use in literature are given below.

2.3.3 Analytical Hierarchy process (AHP)

Introduction

The Analytical Hierarchy Process (AHP) is a method for breaking down a difficult issue into smaller, more manageable chunks. The AHP uses pairwise comparisons to determine the best answer [24]. Saaty was the first to propose the AHP [25]. It is a very beneficial method for making decisions. For the AHP to work, the issue must be broken down into a hierarchical structure, where the higher levels are functionally independent of the lower ones; and the individual elements in each level are likewise functionally independent. Usually, complex problems may be broken down into three levels: the top-level (the problem's aim), the second level (the criteria), and the third level (the solution) (the alternatives) as shown in figure 4. However, in rare cases, there may be more levels beyond the second. It is common to refer to these additional levels as sub-criteria levels. A good question to ask to prioritize the intermediate criteria level is: "Which criterion is most critical for the top level, and to what extent?" To prioritize the third-bottom options concerning the intermediate level of the criteria, the best question to ask is, "Which alternatives are preferred to satisfy the specified criterion, and to what extent?" The AHP analysis provides a CR check, which is a significant strength. One way to assess the consistency of the comparison judgment is via the use of the CR. An assumption of consistency is made when the correlation coefficient is less than 0.01. If the correlation coefficient is more than 0.01 it is considered that inconsistencies in the comparison process have occurred, and the comparison must be updated. The AHP approach may be implemented using the steps listed below [26]:

Methodology

Step 1: Constructing a structuring hierarchy: A issue is broken down into a hierarchy of three levels, with the general goal at the top, choice considerations below it, and an alternate solution below that as shown in figure 4.

Step 2: Construction of the pairwise comparisons: In order to reach a judgement, AHP constructs the pairwise matrix such as

$$A = \begin{bmatrix} x_{11} & x_{12} & \cdots & \cdots & x_{1} \\ x_{21} & x_{22} & \cdots & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & \cdots & x_{nn} \end{bmatrix} \text{Where, } \begin{cases} x_{ii} = 1 \\ x_{ji} = \frac{1}{x_{ij}} \end{cases} \quad (1)$$

The elements x_{ij} are taken from the table 1, which is defined by [25] and comprises preference scales ranging from 1 to 9.

Step 3: Create a normalized comparison matrix A_{norm} by using A.

$$A_{norm} = \begin{bmatrix} y_{11} & y_{2} & \cdots & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & \cdots & y_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ y_{n1} & y_{n2} & \cdots & \cdots & y_{nn} \end{bmatrix} \quad (2)$$

Where

$$w_i = \frac{\sum_{i=1}^{n} y_{ij}}{n} \quad \text{with} \quad \sum_{i=1}^{n} w_i = 1 \quad (3)$$

Step 4: Determine the consistency of the comparison by calculating the Consistency Ratio (CR), which is defined as

$$\text{CR} = \frac{\text{ConsistencyIndex(CI)}}{\text{RandomIndex(RI)}} \quad (4)$$

Where

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (5)$$

In A_{norm}, λ_{max} is the biggest eigen-value, and it is calculated by performing an eigen-value calculation on the A_{norm} matrix. According to the matrix dimension N, as shown in Table 2, the RI value is calculated based on the matrix dimension. The values for RI suggested by the authors Thomas L. Saaty as shown in table 2.

Following that, for each criterion, repeat the pair-wise comparison procedure with regard to the previous hierarchical level; and finally, acquire the global priority weight for each hierarchy level by multiplying the normalized priority weight in the preceding hierarchical levels. Considering all factors while deciding which alternative is best, and then rank the options according to their overall importance.

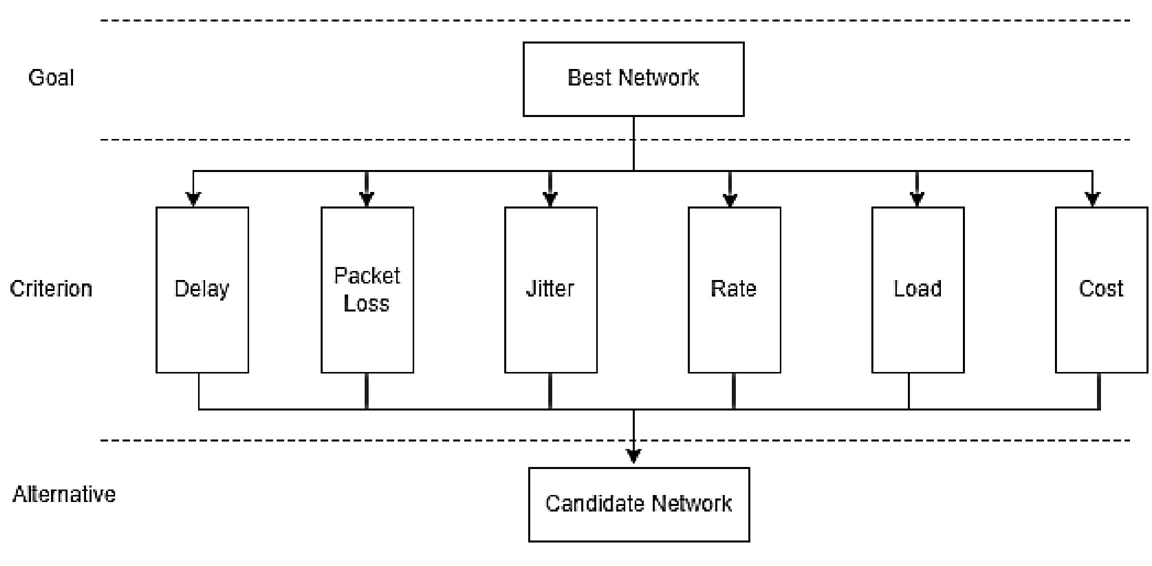

Figure 2.1: An example of the AHP hierarchy structure

Saaty's Scale	The relative importance of the two sub-elements
1	Equally important
3	Moderately important with one over another
5	Strongly important
7	Very strongly important
9	Extremely important
2,4,6,8	Intermediate values

Table 2.1:Saaty's Scale for Pairwise Comparison

The RI value is calculated based on the matrix dimension. The values for RI suggested by the authors Thomas L. Saaty as shown in table 2. These values are used to check the consistency of weights. If the value of RI comes according to the criteria's then it means that user preferences values are set perfectly.

Criteria	3	4	5	6	7	8	9	10
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 2.2:Value of Random Consistency Index RI

AHP in literature

The analytical hierarchy process (AHP) has been used extensively in the literature for decision-making problems. Its applications are not limited to the technology domain, but it has also been applied to decision problems such as project prioritization and selection, strategy development, evaluation of different design options, material selection in the industry, and site selection for enterprise projects such as airports, road, and warehouses. Our research focused on the technology domain, so we will consider it in the network and communication domain.

Some literature adopts this algorithm solitary and addresses the network selection problem, and some use it with the combination of other algorithms. In [27] Goyal at. el used AHP solitary for network selection in the heterogeneous wireless co-existing environment. The author uses the different user business requirements such as conversational, interactive, streaming, and background applications and different networks such as Wi-Fi, WiMAX, 2G, 3G, and 4G. He applied the algorithm to a fast-moving algorithm for different business requirements and concluded that Wi-Fi performance is significantly low when the vehicle moves at high velocity while on the other hand, 2G performs better in that scenario as his data transmission speed is slow but covers a large area.

In [28], Liang et al address the network selection problem in marine internet technology for ships. There are different types of networks available in marines such as satellite networks, ship ad-hoc networks, and coastline networks. These networks differ in cost, performance, coverage area, and capacity as well as reliability and availability. Therefore, it is a challenge for ships to stay connected with the best network in terrestrial environments according to their business requirements. Thus, the author applied the AHP technique to marine internet with the combination of simple additive weighting (SAW) and multiplicative exponent weighting (MEW) and concluded that the proposed methodology performs better for network selection in marine internet technology.

Lahby et al in [29] used the AHP algorithm with the combination of grey relational analysis (GRA) to optimize the network selection mechanism in a heterogeneous wireless co-existing environment. The authors divide the network selection procedure into two phases. The first consist of the calculation of weights of each decision attribute of the target candidate networks and then ranks the candidate networks in the second phase based on the weights calculated in the first phase. He used the AHP algorithm for weighing the network decision attribute and GRA for ranking the candidate networks. He also concluded that the proposed combined algorithm not only ranks the candidate networks accurately but also provides quality of service to the users.

In [30] Chantaksinopas et al address the network selection problem in vehicular Ad Hoc networks (VANET) by applying the AHP Process. The author uses a scenario of moving an internet-connected vehicle from one point to another point and they face different networks. In that way, each network has its decision parameters values, and which network is best suitable for the moving vehicle, is the main problem. Therefore, he addresses this problem by using the AHP technique in VANET. In conclusion, he claims that the AHP process is the optimum method for the selection of networks while moving the vehicle from one point to another point at a different speed. It also provides a rapid and flawless handover mechanism in VANET that meets the severe time limitations.

A variety of other network-selection methods have been created with the help of AHP. Li and colleagues[16] present a utility-based approach for choosing an appropriate interface network in heterogeneous wireless networks. The author proposed the use of the AHP algorithm for weighing the network attributes and utility function for the ranking of the network. The network resource's application need is utilized to derive the network utility function and to calculate the network-resource status. The various access networks are rated, and the best appropriate network is picked using AHP.

Issues

Based on the above mention references authors also highlight some of the drawbacks of using AHP algorithms in network selection problems in the heterogeneous wireless environment along with the benefits. Some of the issues identified in the literature are given below.

- Need more computational time as a result delayed the decision.
- Consumes more memory space as compared to other MCDM algorithms
- Difficult to maintain the flexibility
- Verification and consistency of judgment
- AHP, on the other hand, demands that each network criterion be independent; hence the computing cost of comparing pairs increases as the number of criteria increases. [52]

2.3.4 Technique for order preference by similarity to ideal solution (TOPSIS)

Introduction

THE TOPSIS (Technique for Order Preference by Similarity to Ideal Solutions) is an MCDM technique that takes advantage of the idea of identifying the alternative that is closest to the positive ideal solution and the alternative that is furthest away from the negative ideal solution in order to maximize order preference. According to Yoon and Hwang [31], they were the first to propose the TOPSIS concept. TOPSIS is a highly popular MCDM approach that has been around for quite some time. Euclidean normalization is required for the raw data of the multi-criteria decision matrix.

Methodology

There are six steps to the TOPSIS process, which are listed below:

Step 1: Construct the decision matrix D represented as followed.

$$D = \begin{bmatrix} d_{11} & d_{12} & \dots & \dots & d_{1m} \\ d_{21} & d_{22} & \dots & \dots & d_{2m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \dots & \dots & d_{nm} \end{bmatrix} \quad (6)$$

Where, d_{ij} represents the rating of the alternatives in relation to the criteria.

Step 2: Construct the normalized decision matrix: the Euclidean normalization is used to acquire each element r_{ij}.

$$r_{ij} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^{m} d_{ij}{}^2}}, i = 1, \dots, m, j = 1, \dots, n. \quad (7)$$

Step 3: Create the weighted normalized decision matrix as follows: The following formula is used to construct the weighted normalized decision matrix v_{ij}:

$$v_{ij} = W * r_{ij} where \sum_{i=1}^{m} W_1 = 1 \quad (8)$$

Step 4: Calculation of the ideal A* and anti-ideal A- solutions:

$$A^* = [V_1^*, \dots., V_m^*] and A^- = [V_1^-, \dots., V_m^-] \quad (9)$$

For desirable criteria:

$$V_i^* = max v_{ij}, j = 1, \dots, n \quad (10)$$

$$V_i^- = min v_{ij}, j = 1, \dots, n \quad (11)$$

For undesirable criteria:

$$V_i^* = minv_{ij}, j = 1, \dots, n \quad (12)$$

$$V_i^- = maxv_{ij}, j = 1, \dots, n \quad (13)$$

Step 5: Measure the Euclidean distance between the Positive/ Negative Ideal Solution and candidate alternative, using the following formulas:

$$S_j^+ = \sqrt{\sum_{i=1}^{m} \left(V_i^* - v_{ji}\right)^2}, \quad (14)$$

Where $j = 1,2,3, \dots., n$

And

$$S_j^- = \sqrt{\sum_{i=1}^{m} \left(v_{ji} - V_i^*\right)^2}, \quad (15)$$

Where $j = 1,2,3, \dots., n$

Step 6: As a last step, determine how near the ith option is to the ideal solution by computing C_i as follows:

$$C_j^* = \frac{S_j^-}{\left(S_j^* + S_j^-\right)} \quad (16)$$

Where $j = 1,2,3, \dots., n$

The option with the greatest value of Ci is the one that is the most similar to the ideal solution; as a result, it is regarded as the best alternative.

TOPSIS in Literature

The TOPSIS approach is commonly used in the literature to rank and pick network alternatives; nevertheless, it is plagued by a ranking irregularity that makes it ineffective. An efficient and resilient MCDM algorithm assures that the best alternative ranking order remains unaltered or unchanged when a low-ranked alternative is either removed from or added to the collection of available alternatives, respectively. As a result, when a ranking algorithm is affected by the ranking abnormality issue, the ranking order is not consistent. Consequently, the network selection-decision process may be inefficient [32].

Tan et al. [33] have discovered that, even though TOPSIS suffers from the ranking abnormality issue, it delivers more accuracy in the network rankings when compared to SAW and MEW, respectively.

In [34], Mohamed et al. use a hybrid strategy based on AHP and TOPSIS to network selection in a heterogeneous multi-access environment. Five network interfaces are taken into consideration: UMTS, IEEE802.11b, IEEE802.11a, IEEE802.11n, and Long-Term Evolution (LTE) networks. AHP is used to give weights to the criterion. The findings of the hybrid strategy are compared to those of the standard TOPSIS and DIA approaches. The simulation findings reveal that the TOPSIS and DIA algorithms perform better than they did in the past.

In [35] , Kaleem describes a dynamic wireless-network selection technique based on fuzzy linguistic variables that are divided into two modules: the Vertical Hand-Off Necessity Estimation (VHONE) module, which uses Fuzzy Linguistic Variables (FLVs) to determine the necessity of performing vertical handoff; and the Network Access Technology (NAT) selection module, which uses TOPSIS to select the best available network from WLAN, Wireless Metropolitan Area Network (WMAN), and Wireless WWAN (WWAN). When determining changeover criteria, the following factors are taken into consideration: RSS; delay; jitter; PLR; throughput; network load; security; cost; and MN's velocity.

A new architecture for the selection of wireless access networks in heterogeneous multimedia traffic has been developed by Kaleem et al. [35] to enable smooth mobility and maximum end-user satisfaction. In order to prioritize the various networks in the coverage region for MNs, a ranking method based on Fuzzy TOPSIS (FTOPSIS) is utilized. Results from a single-service scenario reveal that the FTOPSIS scheme outperforms the AHP TOPSIS-based scheme, which employs a numerical weighting approach to evaluate network characteristics, in terms of all four KPIs (drop rate, delay, jitter, and average throughput).

However, although MCDM algorithms are widely used as decision-making tools, they may be plagued by the issue of ranking abnormalities in certain cases. These ranking abnormalities have the potential to degrade the overall precision of the results if they persist. In [36], [37], it is recommended that a multi-attribute network selection via Iterative TOPSIS be used for HWNs access. The authors use an Iterative TOPSIS technique to deal with the ranking abnormality difficulty in TOPSIS; nevertheless, Iterative TOPSIS has the disadvantage of being computationally demanding, which makes it unsuitable for certain applications.

When it comes to multi-criteria selection issues with opposing criteria interests, TOPSIS is an excellent choice since it is intuitively straightforward to grasp and calculate. Due to TOPSIS's lack of weight elicitation and consistency testing, it is susceptible to ranking anomalies and rank reversal [38].

Issues

According to the above mention reference regarding TOPSIS, where the author describes the benefits, there some of the drawbacks of this algorithm also exist.

- Inconsistency in network decision attributes
- Inconsideration of user preferences
- Ranking Abnormality
- Increase computational complexity as the number of networks and user terminals increases

2.3.5 Multiplicative exponent weighting

An MCDM ranking technique, Multiplicative Exponent Weighting (MEW), is based on the weighted products of the criteria for each alternative [39]. It is also known as the Weighted Product Method (WPM) [40]. There is a strong resemblance between MEW and the SAW algorithm. Multiplication and exponentiation are employed instead of addition and multiplication in MEW, which is the fundamental distinction. Decision matrix D is used to solve an MCDM issue using the MEW ranking index for the i^{th} option, A^{i}_{MEW}, as defined by the following equation,

$$A^{i}_{MEW} = \prod_{j=1}^{N} r_{ij}^{w_j} \tag{16}$$

The benefit criteria have a positive weight, whereas the cost criteria have a negative weight. The top ranked alternative A^{i}_{MEW} obtained as

$$A^{i*}_{MEW} = argmax_{i \in M} \prod_{j=1}^{N} r_{ij}^{w_j} \tag{17}$$

The MEW algorithm has been used to develop a variety of network-selection methods. For example, in [40], a MEW algorithm has been used to make vertical handoff decisions that are based on a variety of criteria, including bandwidth, latency, packet-loss-ratio (PLR), and monetary cost per byte of data. The results of simulations for conversational, streaming, interactive, and background service traffics demonstrate that MEW performs similarly to the SAW and Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) algorithms across the four network-traffic classes.

For the HWNs environment, TalebiFard and colleagues [41] proposed a dynamic context-informed network choice for handover based on the modified MEW. The context information is hazy. By including interval data into the MEW, we can better handle the fuzziness of the context information. As opposed to TOPSIS, the improved MEW's network-ranking performance is less computationally costly, more resilient in dynamic decision making under sensitivity analysis, and less prone to ranking irregularity. If a low-ranked alternative is deleted or introduced to the collection of alternatives, a ranking irregularity is triggered by a ranking algorithm.

Issues

MEW has several flaws in its design. This ranking selection penalizes the alternatives with lower criterion scores than the other alternatives. This is owing to the mathematical exponential operation used in the formula. MEW, in contrast to SAW, exhibits nonlinear transformation features.

CHAPTER 3

RESEARCH METHODOLOGY

As we discussed the benefits and drawbacks of our used algorithms in detail earlier in chapter 2. In this chapter, we have introduced an integrated methodology of AHP, TOPSIS, and multiplicative exponent weighting (SAW) to address the issues discussed in the previous chapter. In-network selection problem, every user terminal has different business requirements, user services, and applications requirements, and every user preferred a network with high data transmission at minimum cost. Keeping this in mind that none of any algorithms is present in the literature that addresses the user's preferences, ranking, and selection of the best suitable candidate networks at the same time. Therefore, we have addressed the identified issues in chapter 2 by implementing an integrated algorithm. The integrated algorithm includes three algorithms, AHP, TOPSIS, and MEW.

3.1 Integrated Algorithm Design

The three algorithms discussed in section 2.3.2 are integrated to form an enhanced version of network ranking algorithm in the sense that all criteria of candidate networks are utilized based on their importance along with the user preferences. These three algorithms are AHP, TOPSIS and MEW. AHP has addressed the user preferences issue as identified in the literature. It will first assess the current business requirements of the user, then determine the weights of the decision attribute (known as subjective weights), and then ensures that weights are consistent or not. We have assumed the four business requirements here in our research such as conversational, interactive, background, streaming, and user preferences given by the SAATY scale. The TOPSIS used here to address the ranking abnormality. Ranking abnormality normally occurred due to the disorder of the decision attributes of the network. To overcome the raking abnormality entropy is introduced in the algorithm. The algorithm will calculate the entropy of decision attributes of the candidate network and based on the entropy it will assign the weights to attributes (known as objective weights). Then we have combined the subjective and objective weights to get the integrated weights. In this way, we have taken into account the user preferences and inherent information of decision attributes for candidate networks to ensure the inclusion of user feedback in the network selection procedure. Then we have applied integrated weights on the decision matrix of candidate networks by applying multiplicative exponent weighting to get the integrated normalized matrix. This integrated matrix we used to calculate the ideal and non-ideal solutions according to the desirable and undesirable criteria. Then we calculated the absolute distance of candidate networks from the ideal and non-ideal solutions. The network that has a closer distance from the ideal solution would be considered the optimal solution. Finally, the algorithm will rank the multiple candidate networks available in a heterogenous wireless network environment based on the distance between ideal and non-ideal solutions. A detailed description of our used algorithm and flow chart is given in the following section.

Flow Chart

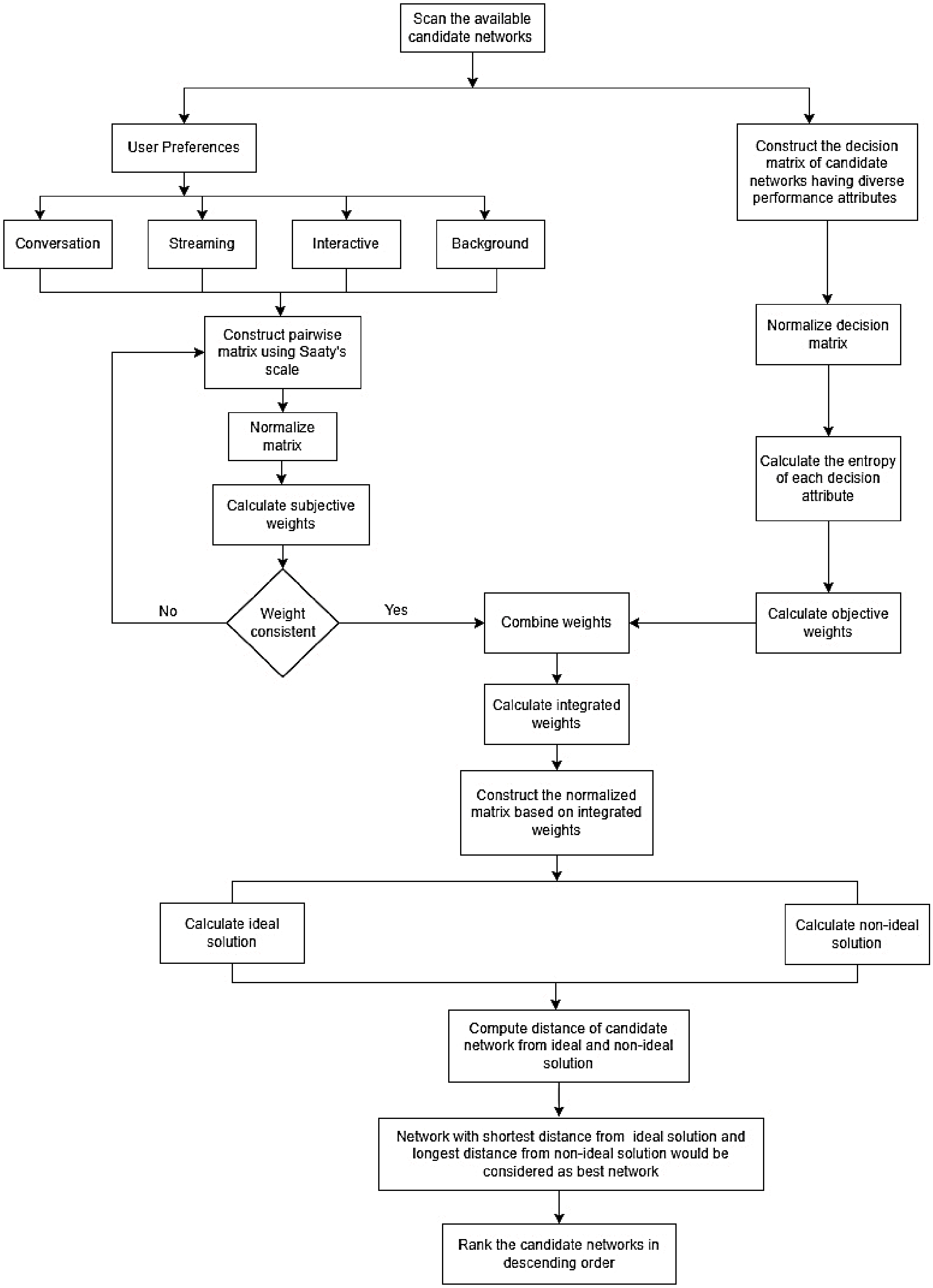

Figure 3.1: Integrated Algorithm Flowchart

3.2 Implementation Steps

The implementation of the integrated network algorithm includes the following steps.

Step 1: Construct the decision matrix D

$$\mathbf{D} = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{m1} & d_{m2} & \cdots & d_{mn} \end{bmatrix} \tag{2}$$

Given that m represents the candidate network and n indicates the number of attributes. $d_{\mathrm{ij}}(i = 1,2,\cdots,m; j = 1,2,\cdots,n)$ indicate the j_{th} characteristics of i_{th} network.

SAATY'S SCALE	RELATIVE IMPORTANCE OF TWO SUB-ELEMENTS
1	Equally important
3	Moderately important with one another
5	Strongly important
7	Very strongly important
9	Extremely important
2,4,6,8	Intermediate value

Table 3.1:Saaty's Scale for Pairwise Comparison

Step 2: Determine the normalize matrix A by using D matrix.

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \tag{3}$$

Where

$$a_{ij} = d_{ij} / \sqrt{\sum d_{ij}^2}, i = 1,2,\cdots,m; j = 1,2,\cdots,n$$

Step 3: Built a hierarchical structure model and subjectively allocated each decision characteristic depending on the type of business, user preference, and network performance. The model of the hierarchical structure shown in Fig. 2.3 shows the highest layer as the best network and the second layer as the decision characteristics. When selecting networks, this research used delay, packet loss, jitter, speed, load, and cost as decision attributes. Candidate networks are the lowest layer. TABLE 3.2 shows the network performance requirements for various company categories. The letters H, M, and L stand for high, medium, and low, respectively. Calculate subjective decision weights based on the relative relevance of each characteristic.

$$\varpi_j^s = \sqrt[n]{\prod_{i=1}^{n} \delta_{ij}}, i, j = 1,2, \cdots, n \tag{4}$$

Where, is the relative relationship of different business types. Normalize the subjective weight $\varpi\delta_{ij}$ get ω_j^S

$$\omega_j^s = \varpi_j^s / \sum_{j=1}^{n} \varpi_j^s, j = 1,2, \cdots, n \tag{5}$$

Business Types	Delay	Packet Loss	Jitter	Rate
Conversational	H	L	H	L
Streaming	L	M	H	H
Interactive	H	H	L	M
Background	L	H	L	M

Table 3.2:Network Performance Requirements for Different Business Requirements

Step 4: Determination of coherence ratio to check whether the weight calculated by pairwise matrix is consistent or not. It can be done by introducing consistency index (CI) and random index (RI). Define the CI.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{6}$$

Calculation of λ_{max} by following method.

$$\lambda_{max} = \frac{\sum_{i=1}^{n} b_i}{n} \text{ such } b_i = \frac{\sum_{j=1}^{n} W_i * a_{ij}}{W_i} \tag{7}$$

Coherence ration calculated by

$$CR = \frac{CI}{RI} \tag{8}$$

CR value is less than 0.1 then pairwise would be consistent. The different RI value are mentioned in Table 3.

CRITERIAS	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
VALUE	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 3.3:Random Consistency Index (RI) value

Step 5: Calculation of entropy of all network attributes used in decision of optimal network. According to the definition of entropy, it can calculate by following formula.

$$e_j = -\sum_{i=1}^{m} p_{ij} \cdot \ln p_{ij} \; j = 1,2,\cdots,n \tag{9}$$

Where

$$p_{ij} = a_{ij} / \sum_{i=1}^{m} a_{ij}, i = 1,2,\cdots,m, j = 1,2,\cdots,n. \tag{10}$$

Step 6: Determine the objective weight ω_J^O of decision attribute based on entropy calculated by equation (8).

$$\omega_j^o = (1 - e_j) / \left(n - \sum_{j=1}^{n} e_j \right), j = 1,2,\cdots,n \tag{11}$$

Although, entropy indicates the information comes up from the decision attributes. If the entropy of any decision attribute has a large value it indicates more information provided by that attribute and has more significance in choosing the optimal network. If the entropy of any decision attribute is 0 then it indicates that the specified attribute does not give any useful information which can use in an optimal network selection mechanism.

Step 7: Add the subjective weight ω_j^s and objective weight ω_j^o to get the integrated weights ω_j for each decision attribute.

$$\omega_j = \alpha\omega_j^S + (1 - \alpha)\omega_j^o, j = 1,2,\cdots,n \tag{12}$$

Where, $\alpha \in (0,1)$, typical value is $\alpha = 0.5$.

Step 8: Construct the normalized weighted matrix.

$$\mathbf{V} = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} \tag{13}$$

Where,

$$v_{ij} = a_{ij} \times \omega_j, i = 1,2,\cdots,m; j = 1,2,\cdots,n.$$

Step 9: Calculation of ideal I^+ and non-ideal I^- solution.

$$I^+ = [v_1^+, v_2^+, \cdots, v_m^+], I^- = [v_1^-, v_2^-, \cdots, v_m^-] \tag{14}$$

For upward criteria

$$\begin{aligned} & v_i^+ = max\{v_{ij}\}, v_i^- = min\{v_{ij}\}, \\ & i = 1,2,\cdots,m; j = 1,2,\cdots,n \end{aligned} \tag{15}$$

For downward criteria

$$v_i^+ = min\{v_{ij}\}, v_i^- = max\{v_{ij}\},$$
$$i = 1,2,\cdots,m; j = 1,2,\cdots,n \quad (16)$$

Step 10: Compute the distance S_i^+ between candidate network i and positive ideal solution I^+,compute the distance S_i^- between candidate network i and negative non-ideal solution I^-.

$$S_i^+ = \sum_{j=1}^{n} \left|v_i^+ - v_{ij}\right|$$
$$S_i^- = \sum_{j=1}^{n} \left|v_{ij} - v_i^-\right|, i = 1,2,\cdots,m \quad (17)$$

Step 11: Network with smallest value of S_i^+ and largest value of S_i^- would be the ideal network named by P.

$$P \sim (min\{S_i^+\}, max\{S_i^-\}, i = 1,2,\cdots,m) \quad (18)$$

Step 12: Determine the effective distance $\boldsymbol{C_i}$ between ideal network $\boldsymbol{P}$ and candidate network $\boldsymbol{i}$.

$$C_i = \sqrt{(S_i^+ - min\{S_i^+\})^2 + (min\{S_i^-\} - S_i^-)^2}$$
$$i = 1,2,\cdots,m \quad (19)$$

In final step, each candidate network i would be ranked according to C_i value.

Step 13: The network which is nearest to C_i value would be considered optimal network for selection.

3.3 Application of Implementation Steps with Example

In this section, the implementation steps discussed in section 3.2 are used for a simple example. We took three different networks such as 3G, 2G, and WLAN having diverse performance attributes in terms of bandwidth, cost, and delay as mentioned in Table 3.4.

Networks	**Bandwidth (mbps)**	**Cost ($)**	**Delay (ms)**
2G	0.1	5	150
3G	2	10	100
WLAN	6	35	80

Table 3.4: Networks and their attributes in example

The user preferences have been fixed by using Saaty's scale where the three attributes are subjectively assigned some constant values based on the relative importance of the attributes. These values are shown in Table 3.5.

Interactive	Bandwidth	Cost	Delay
Bandwidth	1	3	1/2
Cost	1/3	1	1/4
Delay	2	4	1

Table 3.5: User preferences by Saaty's scale

Step 1: The performance attributes in Table 3.4 are used to construct the decision matrix as

$$\mathbf{D} = \begin{bmatrix} 0.1 & 5 & 150 \\ 2 & 10 & 100 \\ 6 & 35 & 80 \end{bmatrix}$$

Step 2: Determine the normalize matrix A by using D matrix as $a_{ij} = d_{ij}/\sqrt{\sum d_{ij}^2}, i = 1,2,3; j = 1,2,3$

$$\mathbf{A} = \begin{bmatrix} 0.0158 & 0.1360 & 0.7605 \\ 0.3161 & 0.2721 & 0.5070 \\ 0.9485 & 0.9525 & 0.4056 \end{bmatrix}$$

Step 3: As the subjective weights are given by $\varpi_j^s = \sqrt[n]{\prod_{i=1}^{n} \delta_{ij}}, i, j = 1,2,3$ in which SIGMA are given in table 3.5. That is

$$\boldsymbol{\delta} = \begin{bmatrix} 1 & 3 & 1/2 \\ 1/3 & 1 & 1/4 \\ 2 & 4 & 1 \end{bmatrix}$$

This means that for bandwidth $\varpi_1^s = \sqrt[3]{(1 * 3 * (1/2))}$ = 1.1447 and similarly for cost $\varpi_2^s = \sqrt[3]{(1/3 * 1 * (1/4))} = 0.4367$ and for delay $\varpi_3^s = \sqrt[3]{(2 * 4 * 1)} = 2$. The normalized values are then ϖ_1^s = 0.3196, ϖ_2^s= 0.1219, and ϖ_3^s=0.5584.

Step 4: Calculation of entropy of all network attributes by following formula

$e_j = -\sum_{i=1}^{m} p_{ij} \cdot \ln p_{ij}\, j$1,2,3 Where $p_{ij} = a_{ij}/\sum_{i=1}^{m} a_{ij}, i = 1,2,3, j = 1,2,3$.
The entropy for bandwidth e_1=0.2700 and similarly for cost e_2=0.3482 and for delay e_3=0.4619.
Step 6: Determine the objective weight ω_j^O of decision attribute based on entropy calculated above by this expression $\omega_j^o = (1 - e_j)/(n - \sum_{j=1}^{n} e_j), j = 1,2,3$

The objective weights calculated for bandwidth ω_1^o =3802 and similarly for cost ω_2^o =3395 and for delay ω_3^o =2802.

Step 7: Add the subjective weight ω_j^s and objective weight ω_j^o to get the integrated weights ω_j for each decision attribute with this expression $\omega_j = \alpha\omega_j^S + (1 - \alpha)\omega_j^o, j =$ 1,2,3 Where, $\alpha \in (0,1)$, typical value is $\alpha = 0.5$. After integrating subjective and objective weights with equal preference we got the weight for bandwidth ω_1 = 0.3499 and similarly for cost ω_2 = 0.2307 and for delay ω_3 = 0.4193.

Step 8: Construct the normalized weighted matrix.

$$\mathbf{V} = \begin{bmatrix} 0.2342 & 0.6311 & 0.8915 \\ 0.6683 & 0.7406 & 0.7521 \\ 0.9816 & 0.9888 & 0.6849 \end{bmatrix}$$

Where,

$$v_{ij} = a_{ij} \times \omega_j, i = 1,2,3; j = 1,2,3.$$

Step 9: Calculation of ideal I^+ and non-ideal I^- solution.

	Bandwidth	Cost	Delay
I^+	0.9816	0.6311	0.6849
I^-	0.2342	0.9888	0.8915

Step 10: Compute S_i^+ and S_i^- by following formulas.

$$S_i^+ = \sum_{j=1}^{n} \left|v_i^+ - v_{ij}\right|$$

$$S_i^- = \sum_{j=1}^{n} \left|v_{ij} - v_i^-\right|, i = 1,2,3,$$

	S_i^+	S_i^-
2G	0.5408	0.3576
3G	0.1366	0.0464
WLAN	0.3576	0.5408

Step 11: Network with smallest value of S_i^+ and largest value of S_i^- would be the ideal network named by P.

$$P \sim (min\{S_i^+\}, max\{S_i^-\}, i = 1,2,3)$$

Step 12: Determine the effective distance $\boldsymbol{C_i}$ between ideal network $\boldsymbol{P}$ and candidate network $\boldsymbol{i}$.

$$C_i = \sqrt{(S_i^+ - min\{S_i^+\})^2 + (min\{S_i^-\} - S_i^-)^2}$$
$$i = 1,2,3$$

Candidate Networks	$\boldsymbol{C_i}$
2G	0.3112
3G	0.0464
WLAN	0.6483

Step 13: The network with the highest value of $\boldsymbol{C_i}$ considered as best network.

CHAPTER 4

RESULTS AND DISCUSSIONS

In this chapter, we showed the performance of the proposed algorithm discussed in previous chapter by applying it on different scenarios in heterogeneous wireless networks. The predefined scenarios showed four user activities (conversation, streaming, interactive, and background) in four distinct networks, each with a different set of decision characteristics (bandwidth, cost, delay, packet loss, load, and jitter). It is observed that the proposed algorithm shows much better network ranking as compared to the existing methods in the literature.

4.1 Scenario 1

Here we consider a heterogeneous network of five different component networks that are characterized by three network attributes that are cost, bandwidth and delay. The simulation environment includes four business requirements such as conversation, streaming, interactive, and background that define the network user preferences. In the following we show the results of AHP, TOPSIS, Multiplicative Integrated AHP-TOPSIS and the proposed Exponential Integrated AHP-TOPSIS.

4.1.1 AHP Implementation

We first consider the use of AHP method discussed in Chapter 2 for ranking of the networks in Scenario 1. Here the decision matrix includes performance attributes of the associated network. Since we have 5 networks and 3 attributes in Scenario 1, the decision matrix will be of size 5 times 3. Their values are inherited from the actual network and are shown in table 4.1 for scenario 1.

Networks	Bandwidth (Mbps)	Cost ($)	Delay (ms)
2G	0.1	5	150
3G	2	10	100
WLAN	6	35	80
4G	10	35	85
WiMAX	20	20	50

Table 4.1:Preliminary performance parameters for scenario 1

Next, pairwise comparisons of the network attributes are obtained from Saaty's scale that contains 1-9 preference scales. These preferences are defined for each of the four user requirements in Table 4.2.

	Conversation			**Streaming**			**Interactive**			**Background**		
	BW	Cost	Delay	BW	Cost	Delay	BW	Cost	Delay	BW	Cost	Delay
BW	1	3	1/3	1	3	6	1	3	1/2	1	4	5
Cost	1/3	1	1/6	1/3	1	3	1/3	1	1/4	¼	1	2
Delay	3	6	1	1/6	1/3	1	2	4	1	1/5	1/2	1
Weights	0.24	0.09	0.65	0.65	0.24	0.09	0.31	0.12	0.55	0.68	0.19	0.11

Table 4.2: Interrelationship of decision attributes in different businesses for scenario 1.

Notice that the last row of Table 4.2 shows the AHP weights that are constructed from the normalized decision matrix as discussed before. Using these weights and the inherent network attributes given in Table 4.1 to obtain the following ranking of the associated networks.

	Conversation		Streaming		Interactive		Background	
	Network value	Ranking	Network value	Ranking	Network value	Ranking	Network value	Ranking
2G	0.2164	3	0.0443	5	0.1867	4	0.0489	5
3G	0.1630	5	0.0786	4	0.1484	5	0.0800	4
WLAN	0.1837	4	0.2027	3	0.1870	3	0.1943	3
4G	0.2170	2	0.2725	2	0.2265	2	0.2672	2
WiMAX	0.2196	1	0.4015	1	0.2510	1	0.4093	1

Table 4.3: AHP ranking of networks for scenario 1.

This shows that based on AHP method the WiMAX network is the best option available in scenario 1 in all the business requirements because the corresponding effective weights are large as compared to other candidate networks. The results are in accordance with the user preferences given in Table 4.2, where the cost and delay parameters have high preferences in conversation plus interactive and streaming plus background requirements, respectively. Since WiMAX has low cost and low delay (Table 4.1) in comparison to other networks, AHP is ranking it as the best network among other options.

4.1.2 TOPSIS Implementation

Next, we implement TOPSIS for ranking of the networks in Scenario 1. For each decision attribute of the candidate network, we compute the entropy to see which decision characteristics perform well and which do not, in the optimum network selection process. The greater the entropy, the greater preference it will get in the network selection process. The entropy of the three decision attributes along with the entropy based calculated weights are shown in Table 4.4.

	Bandwidth	Cost	Delay
Entropy	0.4997	0.6154	0.6725
Weights	0.4126	0.3172	0.2701

Table 4.4:Entropy and Weights for Scenario 1

Networks	Ci value	Ranking
2G	0.0042555	5
3G	0.052238912	4
WLAN	0.147661147	3
4G	0.156739532	2
WiMax	0.265743211	1

Table 4.5: Ranking of networks for scenario 1 with TOPSIS

This shows that based on TOPSIS method the WiMAX network is the best option available in scenario 1 because the associated effective weights are large as compared to other networks. The results are in accordance with TOPSIS calculation given in the Table 4.5 in which algorithm calculate the C_i values and rank candidates networks (in Table 4.1) based on C_i value. Greater the C_i value better the network. Since WiMAX has greater value in comparison to other networks, TOPSIS is ranking it as best network among other options.

4.1.3 Integrated AHP-TOPSIS Implementation

Both the AHP and TOPSIS methods are calculating weights of the performance attributes and these two weights can be integrated by using

$$\omega_j = \alpha\omega_j^S + (1-\alpha)\omega_j^o, j = 1,2,\cdots,n$$

Where, $\alpha \in (0,1)$, with typical value of $\alpha = 0.5$. Also ω_j^S are AHP weights/subjective weights, ω_j^o are TOPSIS weights/objective weights, and ω_j are integrated weights.

Notice that when alpha = 0, the ranking is based on TOPSIS weights and when alpha=1 the ranking is based on AHP weights. The integrated weights at alpha = 0.5 are shown in Table 4.6.

Integrated Weights	Bandwidth	Cost	Delay
Conversation	0.3312	0.2062	0.4624
Streaming	0.5337	0.2835	0.1827
Interactive	0.3661	0.2195	0.4142
Background	0.5480	0.2585	0.1934

Table 4.6: Integrated weights based on AHP and TOPSIS at α = 0.5 in scenario 1

Finally, we calculated C_i values (represent the effective distance between ideal network and candidate network) with both functions such as multiplicative weighting and exponent weighting. And results are significantly improved with multiplicative exponent weighting.

	Conversation		**Streaming**		**Interactive**		**Background**	
	C_i	Ranking	C_i	Ranking	C_i	Ranking	C_i	Ranking
2G	0.1235	2	0.0784	5	0.2887	1	0.0644	5
3G	0.2042	1	0.3272	1	0.2164	2	0.3166	2
WLAN	0.0668	3	0.1606	4	0.0580	4	0.1793	4
4G	0.0445	5	0.1791	3	0.0445	5	0.1873	3
WiMAX	0.0592	4	0.3063	2	0.0889	3	0.3184	1

Table 4.7: Ranking of networks for scenario 1 with multiplicative weighting.

	Conversation		**Streaming**		**Interactive**		**Background**	
	C_i	Ranking	C_i	Ranking	C_i	Ranking	C_i	Ranking
2G	2.8921	1	0	5	0	5	3.1077	1
3G	1.3983	5	1.5092	4	1.4028	4	1.5369	5
WLAN	1.7319	4	1.8895	3	1.7515	3	1.8899	4
4G	1.8801	2	2.0577	2	1.9057	1	2.0582	3
WiMAX	1.8308	3	2.1434	1	1.8771	2	2.1557	2

Table 4.8: Ranking of networks for scenario 1 with multiplicative exponent weighting

For instance, multiplicative function ranks the 3G network for conversation, but it is not cost effective. Although, conversation includes the voice call or text messaging which does not requires a high bandwidth, so it can also be possible with 2G network. In our scenario, multiplicative weighting ranked the 3G as the best network for conversation, but multiplicative exponent weighting ranks the 2G as best networks.

In the case of streaming, the multiplicative algorithm ranks the 3G network as optimal, but the exponent weighting algorithm ranks the WLAN as the best suitable network because streaming entails watching videos, loading movies, and other activities that necessitate a large amount of bandwidth, which WLAN has greater amount of bandwidth in comparison to 3G.

In interactive, the multiplicative exponent weighting also ranks the appropriate network as compared to multiplicative weighting. Interactive includes things like online meetings, video conferences, one-on-one calls, and so on. So, it requires a network with high bandwidth and the lowest possible delay. Multiplicative exponent weighting ranks the 3G network as the best suitable network, but it has a greater amount of delay, which will not address the user business requirements of the interactive well. On the contrary, exponent weighting ranked the WLAN which has a low delay value and greater bandwidth as compared to 3G.

In the case of background, the multiplicative exponent also performs well in ranking the best suitable network. Background business requirement includes the receiving of notification and running the different apps in the background in idle mode of the user terminal, so it does not require a greater amount of bandwidth. Multiplicative weighting ranks the 3G as the best suitable network but it's not cost-effective. On the contrary, exponent weighting ranks the 2G network as it provides a cost-effective solution for background business requirements.

4.2 Scenario 2

Here we consider a heterogeneous network of 5 different component networks that are characterized by five network attributes that are cost, bandwidth, delay, packet loss and jitter. The simulation environment includes 4 business requirements such as conversation, streaming, interactive, and background that define the network user preferences. In the following we show the results of AHP, TOPSIS, Multiplicative Integrated AHP-TOPSIS and the proposed Exponential Integrated AHP-TOPSIS.

4.2.1 AHP Implementation

Here, we also consider the use of AHP method discussed in Chapter 2 for ranking of the networks in Scenario 2. The decision matrix includes performance attributes of the associated network. Since we have 5 networks and 5 attributes in Scenario 2, the decision matrix will be of size 5 times 5. Their values are inherited from the actual network and are shown in table 4.9 for scenario 2.

Networks	Bandwidth (Mbps)	Cost ($)	Delay (ms)	Packet Loss (%)	Jitter (ms)
2G	0.1	5	150	5	120
3G	2	10	100	4	100
WLAN	6	35	80	3	90
4G	10	35	85	2.5	85
WiMAX	20	20	50	1.5	50

Table 4.9: Preliminary performance parameters for scenario 2

Next, pairwise comparisons of the network attributes are obtained from Saaty's scale that contains 1-9 preference scales. These preferences are defined for each of the four user requirements in Table 4.10.

	Conversation					Streaming				
	BW	Cost	Delay	PL	Jitter	BW	Cost	Delay	PL	Jitter
BW	1	3	1/3	2	1/3	1	3	6	2	1
Cost	1/3	1	1/6	1/2	1/6	1/3	1	3	1/2	1/3
Delay	3	6	1	4	1	1/6	1/3	1	1/4	1/6
PL	1/2	2	1/4	1	1/4	1/2	2	4	1	1/2
Jitter	3	6	1	4	1	1	3	6	2	1
Weights	0.14	0.05	0.35	0.08	0.35	0.32	0.11	0.04	0.18	0.32
	Interactive					**Background**				
	BW	Cost	Delay	PL	Jitter	BW	Cost	Delay	PL	Jitter
BW	1	3	1/2	1/3	4	1	4	5	2	6
Cost	1/3	1	1/4	1/4	2	1/4	1	2	1/3	2
Delay	2	4	1	2/3	8	1/5	1/2	1	1/3	1 1/2
PL	3	4	1 1/2	1	8	1/2	3	3	1	5
Jitter	1/4	1/2	1/8	1/8	1	1/6	1/2	2/3	1/5	1
Weights	0.16	0.07	0.31	0.39	0.04	0.45	0.12	0.08	0.28	0.06

Table 4.10: Interrelationship of decision attributes in different businesses in scenario 2

Notice that the last row of Table 4.10 shows the AHP weights that are constructed from the normalized decision matrix as discussed before. Using these weights and the inherent network attributes given in Table 4.9 to obtain the following ranking of the associated networks.

	Conversation		Streaming		Interactive		Background	
	Network value	Ranking	Network value	Ranking	Network value	Ranking	Network value	Ranking
2G	0.2116	2	0.1184	5	0.313	1	0.1651	3
3G	0.1531	5	0.1531	4	0.1531	5	0.1531	5
WLAN	0.1598	4	0.1598	3	0.1598	4	0.1598	4
4G	0.1769	3	0.1769	2	0.1769	3	0.1769	2
WiMAX	0.2979	1	0.2979	1	0.2979	2	0.2979	1

Table 4.11: AHP ranking of networks for scenario 2.

This shows that based on AHP method the WiMAX network is the best option available in scenario 2 in all the business requirements except interactive because the corresponding effective weights are large as compared to other candidate networks. The results are in accordance with the user preferences given in Table 4.10, where the cost and delay parameters have high preferences in conversation plus interactive and streaming plus background requirements, respectively. Since WiMAX has low cost and low delay (Table 4.9) in comparison to other networks, AHP is ranking it as the best network among other options.

4.2.2 TOPSIS Implementation

Next, we implement TOPSIS for ranking of the networks in Scenario 2. For each decision attribute of the candidate network, we compute the entropy to see which decision characteristics perform well and which do not, in the optimum network selection process. The greater the entropy, the greater preference it will get in the network selection process. The entropy of the three decision attributes along with the entropy based calculated weights are shown in Table 4.12.

	Bandwidth	Cost	Delay	Packet Loss	Jitter
Entropy	0.4997	0.6154	0.6725	0.6670	0.6835
Weights	0.2687	0.2065	0.1758	0.1788	0.1699

Table 4.12: Entropy and Weights for Scenario 2

Networks	Ci value	Ranking
2G	0	5
3G	0.067656	3
WLAN	0.097448	2
4G	0.135031	1
WiMAX	0.060157	4

Table 4.13: Ranking of networks for scenario 2 with TOPSIS

This shows that based on TOPSIS method the 4G network is the best option available in scenario 2 because the associated effective weights are large as compared to other networks. The results are in accordance with TOPSIS calculation given in the Table 4.13 in which algorithm calculate the C_i values and rank candidates networks (in Table 4.9) based on C_i value. Greater the C_i value better the network. Since 4G has greater value in comparison to other networks, TOPSIS is ranking it as best network among other options.

4.2.3 Integrated AHP-TOPSIS Implementation

Both the AHP and TOPSIS methods are calculating weights of the performance attributes and these two weights can be integrated by using

$$\omega_j = \alpha\omega_j^S + (1-\alpha)\omega_j^o, j = 1,2,\cdots,n$$

Where, $\alpha \in (0,1)$, with typical value of $\alpha = 0.5$. Also ω_j^S are AHP weights/subjective weights, ω_j^o are TOPSIS weights/objective weights, and ω_j are integrated weights.

Notice that when alpha = 0, the ranking is based on TOPSIS weights and when alpha=1 the ranking is based on AHP weights. The integrated weights at alpha = 0.5 are shown in Table 4.14.

Integrated Weights	Bandwidth	Cost	Delay	Packet Loss	Jitter
Conversation	0.2048	0.1293	0.2677	0.1333	0.2647
Streaming	0.2984	0.1592	0.1117	0.1814	0.2490
Interactive	0.2189	0.1423	0.2440	0.2885	0.1061
Background	0.3605	0.1639	0.1294	0.2303	0.1157

Table 4.14: Integrated weights based on AHP and TOPSIS at α = 0.5 in scenario 2

Finally, we calculated C_i values (represent the effective distance between ideal network and candidate network) with both functions such as multiplicative weighting and exponent weighting. And results are significantly improved with multiplicative exponent weighting.

	Conversation		**Streaming**		**Interactive**		**Background**	
	C_i	Ranking	C_i	Ranking	C_i	Ranking	C_i	Ranking
2G	0	5	0.1238	1	0	5	0.0658	5
3G	0.1357	3	0.1143	2	0.0984	1	0.0868	3
WLAN	0.1519	2	0.0817	4	0.0585	3	0.0763	4
4G	0.1711	1	0.0994	3	0.0309	4	0.1183	1
WiMAX	0.0898	4	0.0271	5	0.0805	2	0.0896	2

Table 4.15:Ranking of networks for scenario 2 with multiplicative weighting.

	Conversation		**Streaming**		**Interactive**		**Background**	
	C_i	Ranking	C_i	Ranking	C_i	Ranking	C_i	Ranking
2G	0.6060	1	0.2382	4	0.2269	5	0.6345	1
3G	0.3494	2	0.2433	3	0.3486	3	0.1200	5
WLAN	0.0869	4	0.2615	2	0.3824	2	0.2555	4
4G	0	5	0.3253	1	0.4324	1	0.3282	2
WiMAX	0.2786	3	0.2366	5	0.3104	4	0.2659	3

Table 4.16: Ranking of networks for scenario 2 with multiplicative exponent weighting.

4.3 Scenario 3

Here we consider a heterogeneous network of 4 different component networks that are characterized by six network attributes that are delay, packet loss, jitter, Rate (Bandwidth), load and cost. The simulation environment includes 4 business requirements such as conversation, streaming, interactive, and background that define the network user preferences. In the following we show the results of AHP, TOPSIS, Multiplicative Integrated AHP-TOPSIS and the proposed Exponential Integrated AHP-TOPSIS.

4.3.1 AHP Implementation

Here, we also consider the use of AHP method discussed in Chapter 2 for ranking of the networks in scenario 3. The decision matrix includes performance attributes of the associated network. Since we have 4 networks and 6 attributes in scenario 3, the decision matrix will be of size 6 times 4. Their values are inherited from the actual network and are shown in table 4.17 for scenario 3.

	Delay (ms)	**Packet Loss (%)**	**Jitter (ms)**	**Rate (Mbps)**	**Load (%)**	**Cost ($)**
WRAN	20	0.03	10	20	100	2.5
IIGN	11	0.02	6	7	100	4
WLAN1	25	0.05	13	13	100	1.2
WLAN2	30	0.03	15	28	100	2

Table 4.17: Preliminary performance parameters for scenario 3

	Conversation						Streaming					
	Delay	PL	Jitter	Rate	Load	Cost	Delay	PL	Jitter	Rate	Load	Cost
Delay	1	4	1	3	5	6	1	1/4	1/6	1/6	1/4	1/3
PL	1/4	1	1/4	1/2	3/2	2	4	1	1/2	1/2	2	2
Jitter	1	4	1	3	5	6	6	2	1	1	2	3
Rate	1/3	2	1/3	1	2	3	6	2	1	1	2	3
Load	1/5	2/3	1/5	1/2	1	2	4	1/2	1/2	1/2	1	2
Cost	1	4	1	3	5	6	3	1/2	1/3	1/3	1/2	1
Weights	0.33	0.08	0.33	0.13	0.06	0.04	0.03	0.17	0.28	0.28	0.13	0.09
	Interactive						**Background**					
	Delay	PL	Jitter	Rate	Load	Cost	Delay	PL	Jitter	Rate	Load	Cost
Delay	1	2/3	8	2	2	4	1	1/3	3/2	1/5	1/2	1/2
PL	3/2	1	8	3	3	4	3	1	5	1/2	2	3
Jitter	1/8	1/8	1	1/4	1/4	1/2	2/3	1/5	1	1/6	1/3	1/2
Rate	1/2	1/3	4	1	2	3	5	2	6	1	2	4
Load	1/2	1/3	4	1/2	1	2	2	1/2	3	1/2	1	3/2
Cost	1/4	1/4	2	1/3	1/2	1	2	1/3	2	1/4	2/3	1
Weights	0.26	0.35	0.03	0.16	0.11	0.06	0.07	0.25	0.05	0.37	0.15	0.10

Table 4.18: Interrelationship of decision attributes in different businesses in scenario 3

Notice that the last row of Table 4.18 shows the AHP weights that are constructed from the normalized decision matrix as discussed before. Using these weights and the inherent network attributes given in Table 4.17 to obtain the following ranking of the associated networks.

	Conversation		**Streaming**		**Interactive**		**Background**	
	Network value	Ranking	Network value	Ranking	Network value	Ranking	Network value	Ranking
WRAN	0.2410	3	0.2526	3	0.2453	3	0.2598	2
IIGN	0.1509	4	0.1703	4	0.1667	4	0.1734	4
WLAN1	0.2766	2	0.2595	2	0.2917	2	0.2540	3
WLAN2	0.3311	1	0.3171	1	0.2958	1	0.3124	1

Table 4.19: AHP ranking of networks for scenario 3.

This shows that based on AHP method the WLAN2 network is the best option available in scenario 3 in all the business requirements because the corresponding effective weights are large as compared to other candidate networks. The results are in accordance with the user preferences given in Table 4.18, where the cost and delay parameters have high preferences in conversation plus interactive and streaming plus background requirements, respectively. Since WLAN2 has low cost and low delay (Table 4.17) in comparison to other networks, AHP is ranking it as the best network among other options.

4.3.2 TOPSIS Implementation

Next, we implement TOPSIS for ranking of the networks in scenario 3. For each decision attribute of the candidate network, we compute the entropy to see which decision characteristics perform well and which do not, in the optimum network selection process. The greater the entropy, the greater preference it will get in the network selection process. The entropy of the three decision attributes along with the entropy based calculated weights are shown in Table 4.20.

	Delay	**Packet Loss**	**Jitter**	**Rate**	**Load**	**Cost**
Entropy	1.3287	1.3322	1.3355	1.2756	1.3862	1.2988
Weights	0.1679	0.1697	0.1714	0.1408	0.1973	0.1526

Table 4.20: Entropy and Weights for scenario 3

Networks	**Ci value**	**Ranking**
WRAN	0.990706	3
IIGN	1.47991	1
WLAN1	0	4
WLAN2	0.990768	2

Table 4.21: Ranking of networks for scenario 3 with TOPSIS

This shows that based on TOPSIS method the IIGN network is the best option available in scenario 3 because the associated effective weights are large as compared to other networks. The results are in accordance with TOPSIS calculation given in the Table 4.21

in which algorithm calculate the C_i values and rank candidates networks (in Table 4.17) based on C_i value. Greater the C_i value better the network. Since IIGN has greater value in comparison to other networks, TOPSIS is ranking it as best network among other options.

4.3.3 Integrated AHP-TOPSIS Implementation

Both the AHP and TOPSIS methods are calculating weights of the performance attributes and these two weights can be integrated by using

$$\omega_j = \alpha\omega_j^S + (1-\alpha)\omega_j^o, j = 1,2,\cdots,n$$

Where, $\alpha \in (0,1)$, with typical value of $\alpha = 0.5$. Also ω_j^S are AHP weights/subjective weights, ω_j^o are TOPSIS weights/objective weights, and ω_j are integrated weights.

Notice that when alpha = 0, the ranking is based on TOPSIS weights and when alpha=1 the ranking is based on AHP weights. The integrated weights at alpha = 0.5 are shown in Table 4.22.

Integrated Weights	Delay	Packet Loss	Jitter	Rate	Load	Cost
Conversation	0.2513	0.1271	0.2530	0.1362	0.1329	0.0991
Streaming	0.1025	0.1715	0.2259	0.2106	0.1674	0.1217
Interactive	0.2173	0.2593	0.1024	0.1569	0.1507	0.1131
Background	0.1189	0.2078	0.1086	0.2731	0.1541	0.1372

Table 4.22: Integrated weights based on AHP and TOPSIS at α = 0.5 in scenario 3

Finally, we calculated C_i values (represent the effective distance between ideal network and candidate network) with both functions such as multiplicative weighting and exponent weighting. And results are significantly improved with multiplicative exponent weighting.

	Conversation		Streaming		Interactive		Background	
	C_i	Ranking	C_i	Ranking	C_i	Ranking	C_i	Ranking
WRAN	0.1818	2	0.2210	1	0.1316	2	0.0963	2
IIGN	0.3359	1	0.1218	2	0.2664	1	0.1564	1
WLAN1	0.1141	3	0.0929	3	0.0528	3	0	4
WLAN2	0	4	0	4	0	0	0.0929	3

Table 4.23: Ranking of networks for scenario 3 with multiplicative weighting.

	Conversation		Streaming		Interactive		Background	
	C_i	Ranking	C_i	Ranking	C_i	Ranking	C_i	Ranking
WRAN	0	4	0.1584	3	0.1253	3	0.1384	3
IIGN	0.2296	2	0.4206	1	0.5661	1	0.0619	4
WLAN1	0.1681	3	0.1612	2	0.2002	2	0.1636	2
WLAN2	0.6176	1	0.0025	4	0	4	0.3753	1

Table 4.24: Ranking of networks for scenario 3 with multiplicative exponent weighting.

We simulated our candidate network (as shown in Table 4.23) with multiplicative weighting and exponent weighting. The results show that the algorithm ranks the candidate network accurately with exponent weighting as compared to multiplicative weighting for different business requirements such as conversation, streaming, background and interactive.

In conversation business requirements, we checked the ranking of candidate networks with multiplicative weighting and it ranks the IIGN network at priority which is expensive network for conversation scenario. But conversation includes the voice calling and text messaging which can be done with a network with low bandwidth and less expensively. When we rank the network with exponent weighting then it ranks WLAN2 network which is cost effective network as compared to IIGN.

In streaming business requirement, it includes the watching and browsing video and these applications are bandwidth hungry. To load and stream the videos, it needs the network with maximum bandwidth and minimum delay, packet loss, jitter. While ranking the candidate networks with multiplicative weighting, it ranks the WRAN at first position, but this network has more delay value and the user experience with streaming will not be the good. On the contrary, when we did rank with multiplicative weighting then the algorithm ranks the IIGN at first and considered it the best suitable network for streaming as it has less delay value as compared to WRAN and video will stream in seamless manner with IIGN.

Interactive includes the video conferencing, virtual meetings and sharing content to multiple individuals. A network with the least amount of delay and the greatest amount of bandwidth is also required for this business requirement. While ranking the candidate network with multiplicative and exponent weighting, both ranked the IIGN at first position but ranking changed for other networks. Multiplicative weighting ranked the WRAN network as second-best suitable network for interactive, but exponent weighting ranked the WLAN1 second best suitable network which has greater bandwidth as compared to WRAN and it can provide the better communication services to interactive business requirement.

Background business requirements include when the device is idle, and the user is not using any bandwidth-heavy applications, as well as when certain apps utilize the internet at the backend. This type of business requirement does not require a network with high bandwidth. A network with low bandwidth can address these business needs. While ranking the candidate networks with multiplicative weighting results shows that the algorithm ranks the IIGN at first position as it has greater value as shown in Table 4.36. This network has greater bandwidth and addresses this business requirement, but it’s not cost-effective. On the contrary, when we ranked the candidate network with exponent weighting then the algorithm ranks the WLAN2 as it has greater bandwidth and delay, but it is cheap.

Based on the above-mentioned result analysis we can say that algorithm based on multiplicative exponent weighting (MEW) ranks the candidate network accurately with respect to the inherent network performance attributes of the candidate network for multiple user business requirements such as conversation, streaming, interactive, and background.

CHAPTER 5

CONCLUSION & FUTURE DIRECTIONS

In this chapter, we'll conclude our work along with some recommendations for future directions.

5.1 Conclusion

The existence of different radio access technologies such as cellular networks (2G,3G,4G,5G), wireless local area networks (WLAN), and Worldwide Interoperability for Microwave Access (WiMAX) in an area makes the heterogeneous wireless network (HWN's) environment. So, when a user terminal moves into HWNs then it experiences multiple networks with different network infrastructure and network performance attributes. In this way, the user terminal is unable to identify the best suitable network which fulfills his current business requirements among conversation, streaming, interactive, and background. To address this problem, multiple network selection algorithms such as multi-attribute decision making (MADM) algorithms (AHP, TOPSIS, SAW, MEW, GRA), utility theory, and intelligent algorithms (game theory, Markov decision process, artificial neural networks) have been used in literature. We have implemented some of these algorithms and analyzed their results in candidate networks ranking. In the analysis, we have identified some of the issues in each algorithm which does not rank the networks cost-effectively.

Some algorithms did not consider the user preferences and some also did not consider the inherent network attributes at the time of network ranking. Like AHP algorithms only consider the user business requirement and preferences and it ranks the network based on the user business requirements, it does not take into account the network attributes while ranking in the HetNets environment. On the contrary, the TOPSIS algorithm does not consider the user business requirements and ranks the candidate network based on their network attributes. Utility theory also ranks the candidate networks in HetNets appropriately, but it does not perform well as the number of networks and their attributes increase. Moreover, Network ranking is also done by some intelligent algorithms such as the Markova decision process, artificial neural networks, and game theory but these types of algorithms are often stuck in a situation in which it is possible to obtain results in the calculation process, but convergence speed becomes slow later, resulted in the higher complications in algorithm and consume more calculation time. Therefore, we adopted the MCDM algorithms to address our research problem as they are less computational complexity and provide the optimal solution. Since our main aim in this research that we are addressing the network ranking based on user preferences and inherent network attributes simultaneously, so we need an algorithm that will rank the candidate network based on user preferences as well as inherent network performance attributes.

We used AHP and TOPSIS algorithm combinedly along with multiplicative exponent weighting (MEW). AHP addressed the user preferences and current business requirements. TOPSIS considered the current network performance attributes while ranking in the heterogeneous wireless network environment. AHP and TOPSIS provide subjective and objective weights respectively. These weights are then applied integrated by the multiplicative exponent weighting algorithm (MEW). Some literature used these weights multiplicatively, but it does not provide a cost-effective ranking. We have applied our integrated algorithm to three different scenarios. Each scenario varies in candidate networks, network criteria, and the value of network attributes. We compared the ranking with multiplicative weighting and multiplicative exponent weighting (MEW). Consequently, an integrated algorithm with MEW provides a cost-effective ranking as compared to an integrated algorithm with a multiplicative ranking.

5.2 Future Directions

Heterogeneous wireless network environment consists of different radio access technologies including cellular networks, wireless local area networks (LAN), and Worldwide Interoperability for Microwave Access (WiMAX). With the advancement in radio access technology and heterogeneous wireless network environment, there is a need for cellular phones that are compatible with all types of networks simultaneously. Though, switching of services from one network to another network having a different network infrastructure (called vertical handover) happens in HWN's environment for the selection of the best suitable network. Therefore, the mobile terminal must have the capability to support all types of networks in HWN's environment. Such user terminal devices are difficult to design, but not impossible. A similar type of project named Google-fi has been launched in the United States which supports all types of networks and started a new era in cellular devices.

Since our research work focused on candidate network ranking improvements in the heterogeneous wireless network environment, so it can apply to the vehicle-to-infrastructure environment. In this infrastructure, internet-connected vehicles move from one point to another point and face different networks. So, it is difficult for these to select the optimal network that will provide efficient data communication services. In this way, our improved ranking algorithm can also improve the network selection mechanism in internet-connected vehicles.

REFERENCES

[1] G. Liang and H. Yu, “Network selection algorithm for heterogeneous wireless networks based on service characteristics and user preferences,” *EURASIP Journal on Wireless Communications and Networking*, vol. 2018, no. 1, p. 241, Dec. 2018, doi: 10.1186/s13638-018-1264-5.

[2] M. Rahnema, “Overview of the GSM system and protocol architecture,” *IEEE Communications Magazine*, vol. 31, no. 4, pp. 92–100, Apr. 1993, doi: 10.1109/35.210402.

[3] E. Dahlman, B. Gudmundson, M. Nilsson, and A. Skold, “UMTS/IMT-2000 based on wideband CDMA,” *IEEE Communications Magazine*, vol. 36, no. 9, pp. 70–80, 1998, doi: 10.1109/35.714620.

[4] A. Ghosh, R. Ratasuk, B. Mondal, N. Mangalvedhe, and T. Thomas, “LTE-advanced: next-generation wireless broadband technology [Invited Paper,” *IEEE Wireless Communications*, vol. 17, no. 3, pp. 10–22, Jun. 2010, doi: 10.1109/MWC.2010.5490974.

[5] R. Chen, L. Pei, J. Liu, and H. Leppäkoski, “WLAN and Bluetooth Positioning in Smart Phones,” in *Ubiquitous Positioning and Mobile Location-Based Services in Smart Phones*, IGI Global, pp. 44–68. doi: 10.4018/978-1-4666-1827-5.ch003.

[6] F. Wang, A. Ghosh, C. Sankaran, P. Fleming, F. Hsieh, and S. Benes, “Mobile WiMAX systems: performance and evolution,” *IEEE Communications Magazine*, vol. 46, no. 10, pp. 41–49, Oct. 2008, doi: 10.1109/MCOM.2008.4644118.

[7] M. Abbak and I. Akduman, “Broadband antenna for GSM, UMTS and LTE Wi-Max applications,” in *2010 10th Mediterranean Microwave Symposium*, Aug. 2010, pp. 60–61. doi: 10.1109/MMW.2010.5605137.

[8] M. Lahby and A. Adib, “Network selection mechanism by using M-AHP/GRA for heterogeneous networks,” in *6th Joint IFIP Wireless and Mobile Networking Conference (WMNC)*, Apr. 2013, pp. 1–6. doi: 10.1109/WMNC.2013.6549009.

[9] S. A. Khan, A. Chaabane, and F. T. Dweiri, “Multi-Criteria Decision-Making Methods Application in Supply Chain Management: A Systematic Literature Review,” in *Multi-Criteria Methods and Techniques Applied to Supply Chain Management*, InTech, 2018. doi: 10.5772/intechopen.74067.

[10] I. Emovon and O. S. Oghenenyerovwho, “Application of MCDM method in material selection for optimal design: A review,” *Results in Materials*, vol. 7, p. 100115, Sep. 2020, doi: 10.1016/j.rinma.2020.100115.

[11] M. Soba, Y. Ersoy, A. Tarakcioğlu Altınay, B. Erkan, and E. Şik, "Application of Multiple Criteria Decision-Making Methods in Assignment Place Selection," *Mathematical Problems in Engineering*, vol. 2020, pp. 1–13, Mar. 2020, doi: 10.1155/2020/6748342.

[12] E. Triantaphyllou, B. Shu, S. Sanchez, and T. Ray, "Multi-criteria decision making: An operations research approach," in *Encyclopedia of Electrical and Electronics Engineering*, vol. 15, 1998, pp. 175–186.

[13] I. Siksnelyte, E. K. Zavadskas, D. Streimikiene, and D. Sharma, "An overview of multi-criteria decision-making methods in dealing with sustainable energy development issues," *Energies*, vol. 11, no. 10. MDPI AG, Oct. 01, 2018. doi: 10.3390/en11102754.

[14] I. Stevic, S. Stević, and Z. Breda, "Application of MCDM Methods to Tourism Evaluation of Cultural Sites," 2019, pp. 357–381. doi: 10.1007/978-3-030-10612-6_24.

[15] A. M. Ghaleb, H. Kaid, A. Alsamhan, S. H. Mian, and L. Hidri, "Assessment and Comparison of Various MCDM Approaches in the Selection of Manufacturing Process," *Advances in Materials Science and Engineering*, vol. 2020, pp. 1–16, Apr. 2020, doi: 10.1155/2020/4039253.

[16] Y. Li, X. Guo, Y. Li, and X. Zheng, "A Utility-Based Network Selection Mechanism in Heterogeneous Wireless Networks," in *2009 International Conference on Wireless Networks and Information Systems*, Dec. 2009, pp. 201–204. doi: 10.1109/WNIS.2009.94.

[17] G.-H. Tzeng and J.-J. Huang, "Multiple Attribute Decision Making: Methods and Applications," 2011.

[18] S. Radouche, C. Leghris, and A. Adib, "MADM methods based on utility function and reputation for access network selection in a multi-access mobile network environment," in *2017 International Conference on Wireless Networks and Mobile Communications (WINCOM)*, Nov. 2017, pp. 1–6. doi: 10.1109/WINCOM.2017.8238177.

[19] P. Kosmides, A. Rouskas, and M. Anagnostou, "Utility-based RAT selection optimization in heterogeneous wireless networks," *Pervasive and Mobile Computing*, vol. 12, pp. 92–111, Jun. 2014, doi: 10.1016/j.pmcj.2013.03.007.

[20] R. K. Goyal, S. Kaushal, and A. K. Sangaiah, "The utility based non-linear fuzzy AHP optimization model for network selection in heterogeneous wireless

networks," *Applied Soft Computing*, vol. 67, pp. 800–811, Jun. 2018, doi: 10.1016/j.asoc.2017.05.026.

[21] S. Khan, M. I. Ahmad, and F. Hussain, "Exponential utility function based criteria for network selection in heterogeneous wireless networks," *Electronics Letters*, vol. 54, no. 8, pp. 529–531, Apr. 2018, doi: 10.1049/el.2017.2673.

[22] A. Ahmed, L. M. Boulahia, and D. Gaïti, "Enabling Vertical Handover Decisions in Heterogeneous Wireless Networks: A State-of-the-Art and A Classification," *IEEE Communications Surveys Tutorials*, vol. 16, no. 2, pp. 776–811, 2014, doi: 10.1109/SURV.2013.082713.00141.

[23] B. H. Massam, "Multi-Criteria Decision Making (MCDM) techniques in planning," *Progress in Planning*, vol. 30, pp. 1–84, Jan. 1988, doi: 10.1016/0305-9006(88)90012-8.

[24] Qingyang Song and A. Jamalipour, "Network selection in an integrated wireless LAN and UMTS environment using mathematical modeling and computing techniques," *IEEE Wireless Communications*, vol. 12, no. 3, pp. 42–48, Jun. 2005, doi: 10.1109/MWC.2005.1452853.

[25] Thomas L. Saaty, *Decision Making for Leaders : The Analytic Hierarchy Process for Decisions in a Complex World*, RWS Publications. RWS Publications, 1990.

[26] D. Podgórski, "Measuring operational performance of OSH management system – A demonstration of AHP-based selection of leading key performance indicators," *Safety Science*, vol. 73, pp. 146–166, Mar. 2015, doi: 10.1016/j.ssci.2014.11.018.

[27] R. K. Goyal and S. Kaushal, "Network Selection Using AHP for Fast Moving Vehicles in Heterogeneous Networks," 2016, pp. 235–243. doi: 10.1007/978-81-322-2650-5_15.

[28] L. Zhou, S.-M. Jiang, and T. Yan, "A Network Selection Scheme Based on the Analytic Hierarchy Process for Marine Internet," *Wireless Communications and Mobile Computing*, vol. 2021, pp. 1–8, Mar. 2021, doi: 10.1155/2021/8861107.

[29] M. Lahby and A. Adib, "Network selection mechanism by using M-AHP/GRA for heterogeneous networks," in *6th Joint IFIP Wireless and Mobile Networking Conference (WMNC)*, Apr. 2013, pp. 1–6. doi: 10.1109/WMNC.2013.6549009.

[30] I. Chantaksinopas, P. Oothongsap, and A. Prayote, "Network selection delay comparison of network selection techniques for safety applications on VANET," in *2011 13th Asia-Pacific Network Operations and Management Symposium*, Sep. 2011, pp. 1–7. doi: 10.1109/APNOMS.2011.6077003.

[31] C.-L. Hwang and K. Yoon, "Methods for Multiple Attribute Decision Making," 1981, pp. 58–191. doi: 10.1007/978-3-642-48318-9_3.

[32] M. Lahby, L. Cherkaoui, and A. Adib, "An enhanced-TOPSIS based network selection technique for next generation wireless networks," in *ICT 2013*, May 2013, pp. 1–5. doi: 10.1109/ICTEL.2013.6632067.

[33] P. N. Tran and N. Boukhatem, "The distance to the ideal alternative (DiA) algorithm for interface selection in heterogeneous wireless networks," in *Proceedings of the 6th ACM international symposium on Mobility management and wireless access - MobiWac '08*, 2008, p. 61. doi: 10.1145/1454659.1454671.

[34] L. Mohamed, C. Leghris, and A. Adib, "A Hybrid Approach for Network Selection in Heterogeneous Multi-Access Environments," in *2011 4th IFIP International Conference on New Technologies, Mobility and Security*, Feb. 2011, pp. 1–5. doi: 10.1109/NTMS.2011.5720658.

[35] F. Kaleem, A. Mehbodniya, A. Islam, K. K. Yen, and F. Adachi, "Dynamic target wireless network selection technique using fuzzy linguistic variables," *China Communications*, vol. 10, no. 1, pp. 1–16, Jan. 2013, doi: 10.1109/CC.2013.6457526.

[36] J. Dhar, K. S. Ravi, and R. K. Yashwanth, "Network Selection in Heterogeneous Wireless Environment: A Ranking Algorithm," in *2007 Third International Conference on Wireless Communication and Sensor Networks*, Dec. 2007, pp. 41–44. doi: 10.1109/WCSN.2007.4475744.

[37] F. Bari and V. Leung, "Multi-Attribute Network Selection by Iterative TOPSIS for Heterogeneous Wireless Access," in *2007 4th IEEE Consumer Communications and Networking Conference*, Jan. 2007, pp. 808–812. doi: 10.1109/CCNC.2007.164.

[38] S. H. Hashemi, A. Karimi, and M. Tavana, "An integrated green supplier selection approach with analytic network process and improved Grey relational analysis," *International Journal of Production Economics*, vol. 159, pp. 178–191, Jan. 2015, doi: 10.1016/j.ijpe.2014.09.027.

[39] F. W. Karam and T. Jensen, "Performance Analysis of Ranking for QoS Handover Algorithm for Selection of Access Network in Heterogeneous Wireless Networks," in *2012 21st International Conference on Computer Communications and Networks (ICCCN)*, Jul. 2012, pp. 1–6. doi: 10.1109/ICCCN.2012.6289261.

[40] E. Stevens-Navarro and V. W. S. Wong, "Comparison between Vertical Handoff Decision Algorithms for Heterogeneous Wireless Networks," in *2006 IEEE 63rd*

Vehicular Technology Conference, pp. 947–951. doi: 10.1109/VETECS.2006.1682964.

[41] P. TalebiFard and V. C. M. Leung, “A dynamic context-aware access network selection for handover in heterogeneous network environments,” in *2011 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, Apr. 2011, pp. 385–390. doi: 10.1109/INFCOMW.2011.5928843.