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# Vertical Handoff Target Selection in a Heterogeneous Wireless Network Using Fuzzy ELECTRE

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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

VERTICAL HANDOFF TARGET SELECTION IN A  
HETEROGENEOUS WIRELESS NETWORK USING FUZZY ELECTRE

A thesis submitted in partial fulfillment of  
the requirements for the degree of

MASTER OF SCIENCE

in

ELECTRICAL ENGINEERING

by

Mukesh Ramalingam

2015

To: Dean Amir Mirmiran  
College of Engineering and Computing

This thesis, written by Mukesh Ramalingam and entitled Vertical Handoff Target Selection in a Heterogeneous Wireless Network using Fuzzy ELECTRE, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

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Jean H. Andrian

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Deng Pan

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Kang K. Yen, Major Professor

Date of Defense: July 2, 2015

The thesis of Mukesh Ramalingam is approved.

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College of Engineering and Computing

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Dean Lakshmi N. Reddi  
University Graduate School

Florida International University, 2015

## DEDICATION

I dedicate this thesis to my parents and friends, whose love, understanding, and sincere support gave me the inspiration to complete this work.

## ACKNOWLEDGMENTS

I am grateful to God for providing me with the capability to finish this difficult task. My sincere gratitude goes to my advisor, Dr. Kang K. Yen, for his candid advice, support, and for helping me successfully finish my dissertation; thank you for believing in me. Thanks to Dr. Deng Pan and Dr. Jean H. Andrian who agreed to become my dissertation committee members. I cannot forget to thank Dr. Shekhar Bhansali, who supported and guided me since the day he took charge of the Department of Electrical and Computer Engineering at FIU; thanks for providing me with all the opportunities to further my career.

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ABSTRACT OF THE THESIS

VERTICAL HANDOFF TARGET SELECTION IN A  
HETEROGENEOUS WIRELESS NETWORK USING FUZZY ELECTRE

by

Mukesh Ramalingam

Florida International University, 2015

Miami, Florida

Professor Kang K. Yen, Major Professor

Global connectivity is on the verge of becoming a reality to provide high-speed, high-quality, and reliable communication channels for mobile devices at anytime, anywhere in the world. In a heterogeneous wireless environment, one of the key ingredients to provide efficient and ubiquitous computing with guaranteed quality and continuity of service is the design of intelligent handoff algorithms. Traditional single-metric handoff decision algorithms, such as Received Signal Strength (RSS), are not efficient and intelligent enough to minimize the number of unnecessary handoffs, decision delays, call-dropping and blocking probabilities.

This research presents a novel approach for of a Multi Attribute Decision Making (MADM) model based on an integrated fuzzy approach for target network selection.

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## LIST OF ABBREVIATIONS

3G: Third Generation

4G: Fourth Generation

AHP: Analytical Hierarchy Process

AI: Artificial Intelligence

AN: Access Network

AP: Access Point

BS: Base Station

CDMA: Code Division Multiple Access

ELECTRE: Elimination and Choice Translating Priority

GRA: Grey Relational Analysis

MADM: Multi Attribute Decision Making

MCDM: Multi Criteria Decision Making

MS: Mobile Station

PoA: Point of Attachment

QoS: Quality of Service

RSS: Received Signal Strength

SAW: Simple Additive Weighting

SIR: Signal to Interference Ratio

TOPSIS: Techniques for Order Preference by Similarity to Ideal Solution

VHITS: Vertical Handoff Initiation and Target Selection

VHO: Vertical Handoff

VoIP: Voice over Internet Protocol

Wi-Fi: Wireless Fidelity

WLAN: Wireless Local Area Network

## INTRODUCTION

Over the past few years, there have been some exciting innovations in wireless communications network technology as shown in Figure 1.1. Wireless and mobile networking is becoming an increasingly important and popular way to provide global information access to users on the move. The demand in the area of wireless communication is to deliver the real-time application over heterogeneous wireless network with assured Quality of Service (QoS) and customer satisfaction. New technological developments like Fourth Generation (4G) wireless systems offer a rich service and applications at high data transfer rates. Most of them usually differ in terms of, but are not limited to, their offered bandwidths, operating frequency costs, coverage areas, and latencies. Currently, no single wireless technology claims to provide cost-effective services, which offers high bandwidths and low latencies to all mobile users in a large coverage area. This is where the need for well-organized vertical handoffs (VHOs) between heterogeneous wireless technologies becomes evident[1].

The term “handoff”, or “handover” [2], refers to the process of transferring a mobile station from one base station (BS) or channel to another. One example, handoff is a continuous transfer of an ongoing voice or video conversation from one channel served by a core network to another channel. In particular, handoff is the process of changing a communication channel (frequency, data rate, modulation scheme, spreading code, or their combination) associated with the current connection, while, a communication session (or call) is in progress.

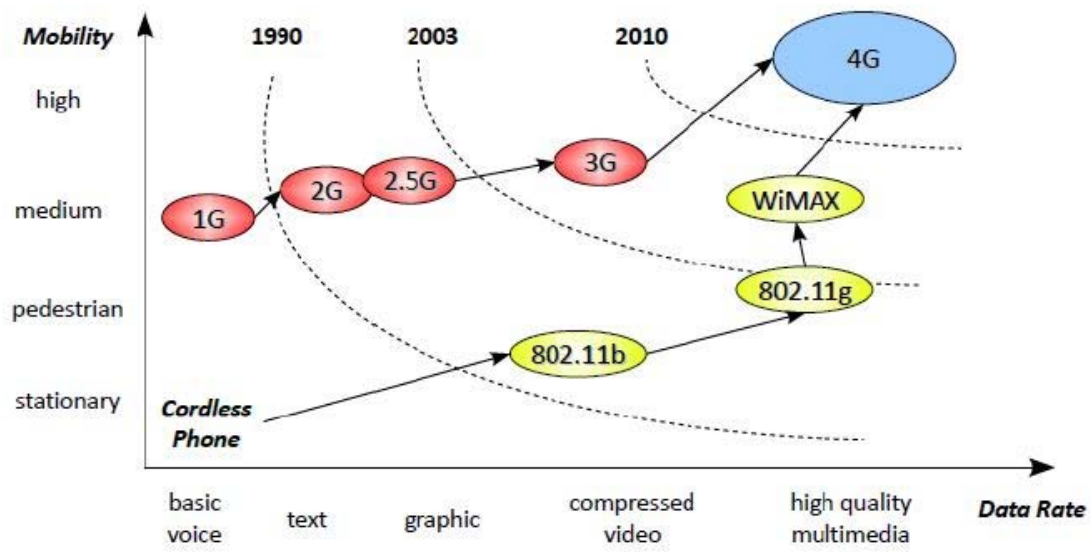


Figure 1.1: Evolution on Wireless Communications

The handoff process has two major stages: handoff initiation, and handoff execution[2]. In the handoff initiation phase, a decision is made regarding the selection of the new Base Station (BS), or Access Point (AP), to which the Mobile Station (MS) will be transferred. In the execution phase, new radio links are formed between the BS/AP and MS, and resources are allocated.

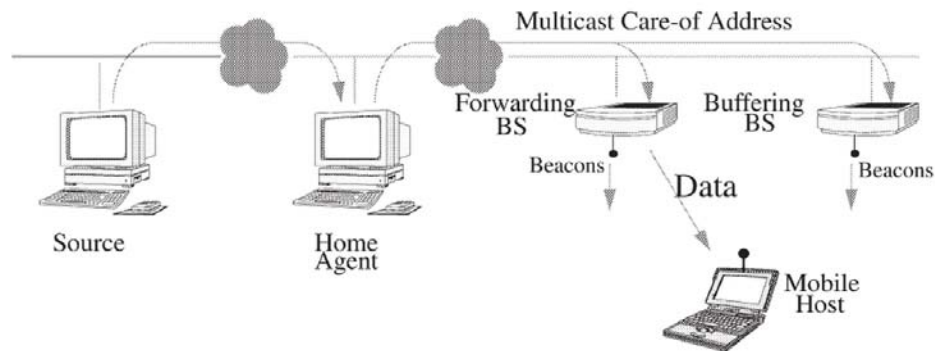


Figure 1.2: Overview of the Handoff System

## 1.1 Motivation and Significance of Research

So far, significant research has been done to achieve continuous mobility while an MS moves across different tiers of heterogeneous wireless network. However, this research mainly focuses on an important aspect of continuous mobility: vertical handoff initiations and decisions. Horizontal handoff decisions between the cells of same tier are made mainly on the basis of Received Signal Strength (RSS), whereas decisions for vertical handoffs are typically performed based on more than one network's parameters, including, but not limited to, RSS, MS-Velocity, Security, Cost, and QoS parameters. These decisions often incorporate network-operators policies and end-users preferences as well.

Many of the existing handoff algorithms, which are based on a single metric, such as RSS, do not exploit the benefits of multi-criteria and inherent knowledge about the sensitivities of these handoff parameters in heterogeneous wireless network systems. Further, these algorithms do not take QoS into account to maximize the end-users satisfaction. Factors like available network bandwidth, latency, security, usage cost, power consumption, battery status of MS, and user preferences should be thoroughly considered while performing these handoff decisions.

In nearly all the multi-criteria hand-off schemes, assigning different weights helps prioritize network parameters. Most of the time, the assignment of these weights is done manually without considering how much weight is needed for a certain network parameter. This could lead to a degraded handoff performance if one parameter is given

higher weight as compared to another, especially during an ongoing user-session, such as a Voice over IP (VoIP) conversations, where achieving a minimum level of QoS is essential. Thus, calculating the correct weights for network parameters is an important task when operating in a heterogeneous wireless environment. Furthermore, nearly all handoff schemes utilize crisp values for these weights, ignoring the fact that typical values of parameters in a wireless network are not precise and are characterized by inherent uncertainty. Therefore, in order to guarantee the quality of the currently utilized service, proper weight assignment, especially for QoS related parameters, is of utmost importance and should be done very carefully. In addition, the fuzzy nature of these values should be kept in mind while assigning these weights.

The ELECTRE1 method overcomes the drawbacks of other MADM (Multi Attribute Decision Making) methods by not assuming the performances of the alternatives, relative to the criteria. Unlike many other MCDM (Multi Criteria Decision Making) methods, ELECTRE1 do not assumed that the criteria are mutually difference independent. It also does not assume that the performances of the alternatives with respect to different criteria can be evaluated on the basis of a common scale. While other MADM like AHP (Analytical Hierarchy Process) requires that comparisons between both alternatives and criteria can be quantified, it also requires the assumption that the performance of the alternatives with respect to each of the criteria can be evaluated on the basis of a common ratio scale.



## 1.2 Research Contribution

In this research work, an intelligent, scalable, and flexible hybrid scheme is proposed to perform intelligent and efficient target network selection decisions. In the proposed scheme, different parameters of all available candidate networks are utilized to determine a new PoA (Point of Access), or an access network, that can best fulfill the end-user's requirements. The target network selection scheme utilizes certain ranking algorithms to rank the available networks based on multiple criteria. The proposed scheme intends to maximize the end-user's satisfaction, taking into account the quality of the currently utilized service that the end-user experiences at the mobile terminal.

The fuzzy set theory is ideally suited for handling these ambiguities encountered in solving MADM (Multi Attribute Decision Making) problems. Fuzzy logic, together with fuzzy arithmetic, could be used to develop the procedures for treating vague and ambiguous information which is frequently expressed with linguistic variables and whose inaccuracy is not particularly due to the variability of the measures, but due to the uncertainties inherent in the available information.

## 1.3 Organization of the Thesis:

The organization of this thesis is as follows. Chapter 2 provides a brief background on the process of handoff, followed by a comprehensive overview of the related work in the area of vertical handoff decisions. In Chapter 3, an overall framework

of the proposed handoff scheme is presented. Simulation and experimental results are presented in Chapter 4, and finally, Chapter 5 concludes this research work

## BACKGROUND AND RELATED WORK

This chapter begins by providing a background related to the handoff process followed by a comprehensive survey of different approaches to make vertical handoff decisions. Through the literature review, the available handoff algorithms can be grouped into different categories based on the main handoff decision criterion used[1]: RSS based, multiple-criteria decision based.

### 2.1 Handoff Process Background

#### 2.1.1 Handoff Classification:

Handoffs can be classified into several ways as discussed below:

*Horizontal and Vertical Handoff:* Depending on the type of network technologies involved, handoff can be classified as either horizontal or vertical[3]. Traditional handoff, also called horizontal or intra-system handoff, occurs when the MS switches between different BSs or APs of the same access network. For example, horizontal handoff typically happens when the user moves between two geographically adjacent cells of a third generation (3G) cellular network. On the other hand, vertical handoff or inter-system handoff involves two different network-interfaces representing different wireless access networks or technologies, figure 2.1 depicts two types of handoffs in heterogeneous wireless networks, where horizontal handoff occurs between two WLANs, and vertical handoff occurs between a WLAN and a CDMA network.

*Hard and Soft Handoff:* This classification of handoff depends on the number of BSs and/or APs to which an MS is associated with at any given moment[3]. Hard handoff, also called “break before make”, involve only one BS or AP at a time. The MS must break its connection from the current access network before it can connect to a new one[4]. In a soft handoff, also called “make before break”, an MS can communicate and connect with more than one access network during the handoff process.

*Mobile-controlled, Mobile-assisted, and Network-controlled Handoff:* As the name suggests, these types of handoff classifications are based on the entity, MS or access network, which make the handoff decisions[5]. Mobile-assisted handoff is the hybrid of mobile-controlled and network-controlled handoff where the MS makes the handoff decisions in cooperation with the access network.

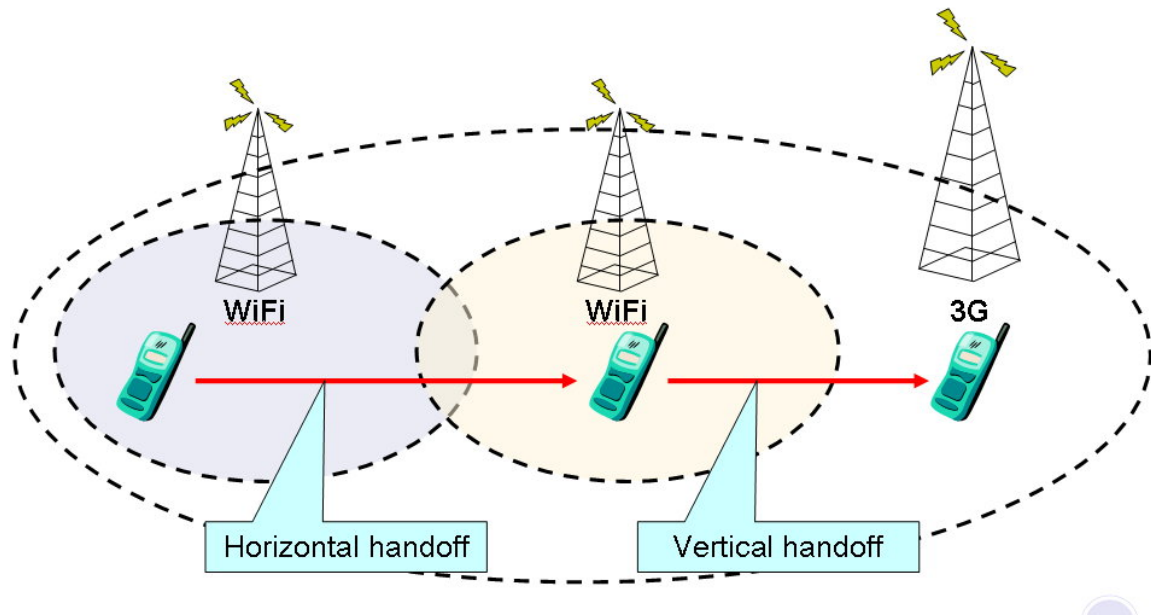


Figure 2.1: Horizontal and Vertical Handoff in Heterogeneous Wireless Networks

### 2.1.2 Desirable Features of Handoff

Figure 2.2 [5] describes several desirable features of handoff algorithms as mentioned in the literature [5, 6]. Some of these features are described below:

- *Speed*: Handoff should be fast enough to avoid service degradation and/or interruption at the MS. Mobility of an MS at high speed requires the handoff to be done promptly.
- *Reliability*: Handoff should be reliable such that the MS will be able to maintain the required QoS after handoff.
- *Successful*: Free channels and resources must be available at the target access network in order to make the handoff successfully.
- *Number of Handoffs*: The number of handoffs must be minimized. Excessive number of handoffs results in a poor QoS and excessive processing overheads as well as power loss, which is a critical issue in MSs with limited battery power.
- *Multiple criteria Handoff*: The target access network should be intelligently chosen based on multiple criteria. Identification of a correct AN (Access Network) prevents unnecessary and frequent handoffs.

### 2.1.3 Vertical Handoff Process

The traditional horizontal handoff research involves handoff decisions based on the manual evaluation of RSS measured at the MS to support the “Always Best Connected” communications. These traditional handoffs are triggered when the RSS value of the serving BS falls below a specified threshold. On the other hand, an MS in a

heterogeneous wireless environment can move between different ANs with different functionality and characteristics (bandwidth, latency, power consumption, cost, etc.) which cannot be directly compared. Hence, in case of vertical handoffs, RSS itself is not sufficient for making efficient and intelligent handoff decisions; other system metrics including, but not limited to, cost, network-load and performance, available bandwidth, security, and user preferences should be taken into consideration as well. On the other hand, the inclusion of multiple metrics increases the complexity of vertical handoff decisions and makes the entire process more challenging. A vertical handoff comprises of three phases as follows[7]:

*Network Discovery:* An MS with multiple active interfaces can discover several wireless networks based on broadcasted service advertisements from these wireless networks. However, keeping all these interfaces active all the time can significantly affect the battery power of the MS.

*Handoff Triggering and Decision:* This is the phase where the decision regarding “when” to perform handoff is made. In this phase, the target wireless access network is selected based on multiple criteria, as discussed before.

*Handoff Execution:* This is the last phase of the vertical handoff process where the actual transfer of the current session to the new AN takes place. This requires the current network to transfer routing and other contextual information related to the MS to the newly selected AN as quickly as possible.

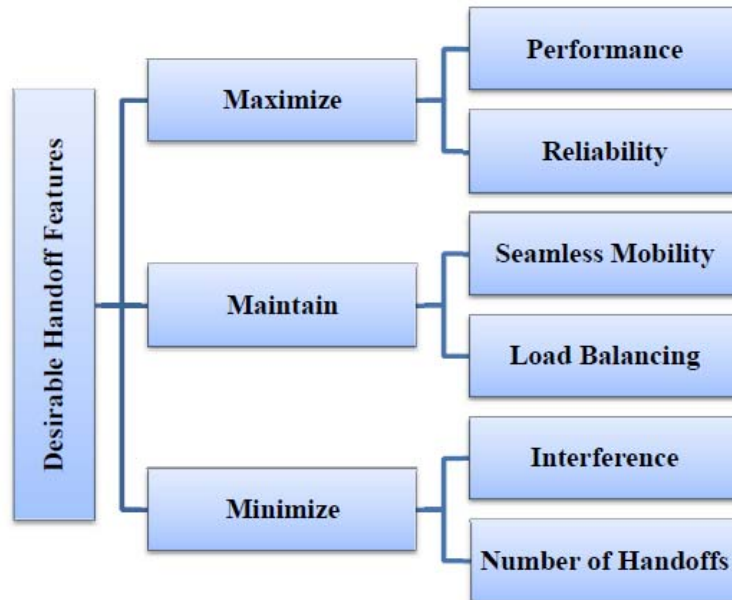


Figure 2.2: Desirable Handoff Features

#### 2.1.4 Vertical Handoff Criteria and Metrics:

The metrics of vertical handoff are as follows:

- **Received Signal Strength:** This criterion is simple, direct, and widely used in both horizontal and vertical handoffs. RSS is easy to measure and is directly relevant to the QoS of an application. Also, RSS readings are inversely proportional to the distance between the MS and the BS, and could result in excessive and/or unnecessary handoffs.
- **Available Bandwidth:** Measured in bits/sec (bps), available bandwidth is used to determine traffic-loading conditions of an AN, and is a good measure of available communication resources at the BS.

- **Network Connection Duration:** This is the amount of time that the MS remains connected to a specific AN. This time duration depends on the location and velocity of the MS, which in turn affect its RSS. Due to different coverage areas in heterogeneous wireless networks, the evaluation of this criterion is very important to determine two factors: 1) The triggering conditions required for the handoff at the right time in order to maintain a satisfactory QoS while avoiding wastage of network resources and 2) to reduce the number of unnecessary handoffs. For example, a hasty handoff from an IEEE 802.11 WLAN to a 3G cellular network would result in network resources being wasted. On the other hand, delaying the handoffs between these networks would result in handoff failures and subsequent call drops. Statistics, such as total time spent in an AN and arrival time of a new call in the network, can also be used as handoff criteria.
- **Monetary Cost:** Different operators may operate heterogeneous wireless networks and may have varying costs associated with them. The network with the least cost should be a preferred target of handoff.
- **Handoff Latency:** For an MS, handoff latency is defined as the elapsed time between the last packet received from the old AN, and the arrival of the first packet via the new AN after a successful handoff. This metric varies considerably between various heterogeneous wireless technologies.
- **Security:** Certain applications require that the confidentiality, and/or the integrity of the transferred data be preserved. This metric can be used to handoff to a network that offers higher security as compared to other available networks.



- **Power Consumption:** Handoff process demands a fair amount of power consumption. If an MS were running low on battery power, it would be preferable to handoff to a target AN that would help extend the MS's battery life.
- **Velocity:** Velocity is an important decision factor as it relates to the network-connection-duration metric and location of the MS. An MS travelling at a very high speed may result in excessive handoffs between wireless networks.

## 2.2 Literature Review

### 2.2.1 RSS Based Algorithms:

In this approach, the RSSs of the different candidate ANs are measured over time and the BS or AP with the strongest signal strength is selected to carry out a handoff[8]. A number of studies have been conducted in this area due to the simplistic nature of this approach. Since heterogeneous wireless networks comprise of different wireless technologies, their RSSs cannot be compared directly, and thus relative RSS does not apply to vertical handoff decisions[9]. On the other hand, other network parameters such as bandwidth, are typically combined with RSS when making decisions for vertical handoffs[10][11]. It is important to mention that the possible signal fluctuations due to multipath fading can result in the undesirable so-called “ping-pong effect”, i.e. unnecessary handoffs that increases the probability of call failures and drops during the handoff process.

### 2.2.2 SIR Based Algorithms:

Signal to Interference Ratio is typically used to measure the quality of communication. In this approach, a handoff is initiated if the Signal to Interference Ratio of the current PoA, BS or AP, is lower than the threshold as compared to the SIR of the target network.

### 2.2.3 Velocity Based Algorithms:

Different techniques have been presented to perform handoffs, using velocity as the main decision criterion[11]. If the MS in a heterogeneous environment moves with a relatively high velocity, the probability of a call drop may be higher due to excessive delays caused by the handoff process[12]. Based on the velocity of the MS, different values of the velocity threshold can be used to make handoff decisions. This is due to the fact that the sojourn time of slower moving MS is much higher than the MS travelling with a relatively higher speed[13].

### 2.2.4 Direction Based Algorithms:

For high mobility MSs, this category of algorithms can make effective handoff decisions based on whether the MSs are moving towards or away from the network (BS/AP). This can improve handoff performance by lowering the mean number of handoffs, thus reducing the overall handoff delays[14]–[16].

### 2.2.5 Minimum Power Algorithms:

The proposed technique attempts to find a pair of networks with available channel that has a SIR based on minimum transmitted power[17]. This algorithm reduces call-dropping probability, but increases the number of unnecessary handoffs.

### 2.2.6 USER PREFERENCE BASED ALGORITHMS:

These approaches mainly take into account the end-users' preferences in terms of MS's power consumption, associated service cost, offered security, and the QoS provided by a candidate network. Most of these approaches are developed to maximize the end-user's satisfaction while utilizing non-real-time applications[18]–[21].

### 2.2.7 Context Aware Based Algorithms:

The approaches presented in [21], [22]–[25] use context information to perform intelligent handoff decisions. Contextual changes are also taken into account to determine the necessity of handoffs. Context information is collected from the following:

- *Mobile Station*: Capabilities, remaining battery power, location, and velocity.
- *User*: User's preferences in terms of preferred network usage-cost, security, and desired QoS.
- *Candidate Network*: Provided QoS, coverage area, available bandwidth, security offerings, cost of usage, and latency.
- *Application*: QoS requirements based on the type of service (Conversational, Background, Streaming, etc.) needed.

### 2.2.8 Cost Function Based Algorithms:

The cost function based approaches[3], [27]–[29] combine different system's metrics in a cost function that represents a measure of the benefit obtained by handing off to a particular candidate network. For every candidate network, the sum of weighted

functions of specific parameters is evaluated to produce the final cost of the network. The general form of a cost function for a wireless network is given by:

$$f_n = \sum_s \sum_i w_{s,i} \cdot p^{n_{s,i}} \quad (2.1)$$

Where  $p^{n_{s,i}}$  is the cost related to the  $i^{th}$  parameter for providing service  $s$  on network  $n$ ,  $w_{s,i}$  is the importance weight associated with the  $i^{th}$  parameter and  $\sum_i w_i = 1$ .

Two commonly used cost functions found in literature are provided in Equations

$$c_s^n = \sum w_{s,j}^n Q_{s,j}^n \quad \text{s.t. } E_{s,j}^n \neq 0 \quad \forall s, i \quad (2.2)$$

Where  $C_s^n$  is the per-service cost for network  $n$ ,  $Q_{s,j}^n$  is the normalized QoS provided by network  $n$  for parameter  $j$  and service  $s$ ,  $w_{s,j}^n$  is the weight which indicates the impact of the QoS parameter on the user or the network, and  $E_{s,j}^n$  is the network elimination factor, indicating whether the minimum requirement of parameter  $j$  for service  $s$  can be met by network  $n$ . The second cost function represents the total cost as the sum of all the weighted cost associated with all QoS parameters used.

$$Q_{s,j}^n = w_c C_i + w_s S_i + w_p P_i + w_d D_i + w_f F_i \quad (2.3)$$

Where  $Q_i$  is the quality factor of network  $i$ ;  $C_i, S_i, P_i, D_i, F_i$  are the cost of the service, offered security, MS's power consumption, and network conditions & performance, and  $w_c, w_s, w_p, w_d, w_f$  are the associated weights to the network parameters selected. A normalization process

$$Q_i = \frac{w_c \left( \frac{1}{C_i} \right)}{\max \left( \frac{1}{C_1}, \dots, \frac{1}{C_n} \right)} + \frac{w_s S_i}{\max(S_1, \dots, S_n)} + \frac{w_p \left( \frac{1}{P_i} \right)}{\max \left( \frac{1}{P_1}, \dots, \frac{1}{P_2} \right)} + \frac{w_d D_i}{\max(D_1, \dots, D_n)} + \frac{w_f F_i}{\max(F_1, \dots, F_n)} \quad (2.4)$$

is used to calculate a normalized quality factor for network  $n$ . This is required as each network's parameter has a different unit.

### 2.2.9 Multiple Criteria Based Algorithms:

This approach is based on a typical MADM problem where the selection of an access network is performed based on multiple attributes measured from all available candidate networks. Some of these MADM techniques are as follows:

- Simple Adaptive Weighting (SAW): SAW is the best known and widely used scoring method utilized by [27], [30]–[34] to rank candidate networks. A weighted sum of all the network attributes is used to determine the overall score of each candidate network. The score of the  $i^{th}$  candidate network is obtained by adding the normalized contributions from each metric  $r_{i,j}$  multiplied by the weight  $w_j$  assigned to the  $j^{th}$  metric. The selected network has the highest score and is given by:

$$A_{SAW} = \operatorname{argmax}_i \sum_{j=1}^N w_j r_{ij} \quad i \in M \quad (2.5)$$

$$r_{ij} = \frac{x_{ij}}{x_j^+} \quad \text{where } j \in B \quad (2.6)$$

Or

$$r_{ij} = \frac{x_j^-}{x_{ij}} \quad \text{where } j \in C \quad (2.7)$$

$$x_j^+ = \max_{i \in M} x_{ij} \quad (2.8)$$

$$x_j^- = \min_{i \in M} x_{ij} \quad (2.9)$$

$$\sum_{j=1}^N w_j = 1 \quad (2.10)$$

Where,  $x_{i,j}$  is the  $j^{th}$  attribute of the  $i^{th}$  network,  $N$  is the number of parameters,  $M$  denotes the number of candidate networks,  $B$  represents benefit type criteria (like throughput), and  $C$  represents cost type criteria (like delay).

- **Multiplicative Exponent Weighting (MEW):** In these techniques[30], [35], [36], a handoff decision matrix is formed where a particular row and column corresponds to the  $i^{th}$  candidate network and  $j^{th}$  attribute of the network, respectively. The weighted product of the attributes is used to determine the score  $S_i$  of the  $i^{th}$  network as follows:

$$S_i = \prod_{j=1}^N x_{ij}^{w_j} \quad (2.11)$$

Where  $x_{ij}$  denotes  $j^{th}$  attribute of the  $i^{th}$  candidate network,  $w_j$  denotes the weight of attribute  $j$ , and  $\sum_{j=1}^N w_j = 1$ . The rank of the selected network is given by:

$$A_{MEW} = \arg \max_i S_i \quad i \in M \quad (2.12)$$

Where  $M$  denotes the number of available candidate networks.

- **Techniques for Order Preference by Similarity to Ideal Solution:** The selected network in the TOPSIS schemes [30], [31], [33] is the one that is closest to the ideal solution and the farthest from the worst-case solution. This ideal solution is

obtained by using the best value for each metric. The selected network is given by:

$$A_{TOPSIS} = -arg \max_i C_i \quad i \in M \quad (2.13)$$

where  $C_i$  denotes the relative closeness (similarity) of the candidate network  $i$  to the ideal solution. This technique can be applicable to problems spaces for the attributes with monotonically increasing or decreasing levels of utility. The algorithm calculates perceived positive/negative ideal solutions based on the range of attribute values available for the alternatives.

- Elimination and Choice Translating Priority (ELECTRE): This is another scheme[31], [34], [37], [38] used to rank the alternatives. The authors utilize a reference vector of attributes as an ideal alternative to adjust the raw attributes of the candidate networks. A matrix containing the difference between the attribute values of this reference vector and other alternatives is formed, and normalized. The resultant matrix contains attributes that have a monotonically decreasing utility. Weights are assigned to each attribute to take into account their relative importance. Finally, the concept of concordance (measure of satisfaction) and discordance (measure of dissatisfaction) is applied during the comparison of each alternative network with others. A candidate network with the highest value of concordance index and lowest value of discordance index would be the preferred network.

- Analytic Hierarchy Process and Grey Relational Analysis (GRA): The AHP decomposes the network selection problem into several smaller problems and assigns a weight value to each of them[34], [39]–[41]. GRA is then used to rank the candidate networks, and the network with the highest ranking value is chosen. The Grey Relational Coefficient (GRC) of each network, which describes the similarity between each candidate networks and the ideal network, is calculated. The selected network is given by:

$$A_{GRA} = \operatorname{argmax}_i \Gamma_{0,i} \quad i \in M \quad (2.14)$$

Where  $\Gamma_{0,i}$  is the GRC of the  $i^{th}$  network.

The authors propose a combined application of AHP and Grey System theory to evaluate the users' preferences and service requirements, and combine the QoS requirements with the candidate networks' performances to make the final network selection decisions.

- VIKOR: VIKOR is an MADM method[31], [32], [42], [43] that is developed to optimize the multi-attribute based complex systems. It is a compromise programming approach that is based on an aggregating function that represents closeness to the ideal solution. Thus, VIKOR is able to determine a compromise-ranking list of alternatives in the presence of conflicting criteria.

A comparative analysis of some of these methods with numerical examples, for voice and data applications, in a 4G wireless system is proposed[30]. It is shown that methods such as SAW, TOPSIS, and VIKOR are suitable for voice connections, whereas GRA and MEW provide a better performance for data connections.



Another comparison of these methods, using bandwidth, delay, jitter, and BER as system's parameters[31]. GRA provides a slightly higher bandwidth and lower delay for Interactive and Background traffic classes. Results also demonstrated that the performance of these algorithms depends on the priority weights assigned to the system parameters.

### 3.1 MADM:

The term MADM stands for Multi-Attribute Decision Making method. MADM methods are used for circumstances that necessitate the consideration of different options that cannot be measured in a single dimension. Each method provides a different approach for selecting the best among several preselected alternatives. The MADM methods help DMs (Decision Maker) learn about the issues they face, the value systems of their own and other parties, and the organizational values and objectives that will consequently guide them in identifying a preferred course of action [44]. The primary goal in MADM is to provide a set of attribute-aggregation methodologies for considering the preferences and judgments of DMs. Several methods have been proposed for solving MADM problems (i.e., Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS), and ELECTRE).

In this study, we use the Electre method. The main strength of this particular tool lies in its non-compensatory nature[45]. ELECTRE needs less input compared to AHP, eliminates the necessity for pairwise comparisons and can be performed easily when the number of alternatives and criteria are very large[36]. Other advantages of ELECTRE include the ability to take purely ordinal scales into account without the necessity of converting the original scales into abstract ones with an arbitrary imposed range (thus maintaining the original concrete verbal meaning), and the ability to take into consideration the DM's indifference and preference thresholds when modeling the imperfect knowledge of data[46].

### 3.2 ELECTRE:

The ELECTRE method is a family of MADM methods developed to rank a set of alternatives. Soon after the introduction of the first version known as ELECTRE I, this approach has evolved into a number of variants. Today, the most widely used versions are known as ELECTRE II and ELECTRE III [47]. Electre is a procedure that sequentially reduces the number of alternatives. The DM is faced within a set of non-dominated alternatives. The Electre method has been extensively applied in many real-world applications, including environment management, education systems, and water resources planning. The ELECTRE (Elimination Et Choix Traduisant He realite) is based on the concept of ranking by paired comparisons between alternatives on the appropriate criteria[48]. An alternative is said to dominate the other if one or more criteria are met (compared with the criterion of other alternatives) and it is equal to the remaining criteria. Ranking relations are between two alternatives.

### 3.3 Fuzzy ELECTRE:

In traditional ELECTRE methods, the weights of the criteria and the ratings of alternatives on each criterion are known precisely, and crisp values are used in the evaluation process. However under many conditions, exact or crisp data are inadequate to model real-life situations. Therefore, these data may have some structures such as fuzzy data, bounded data, ordinal data and interval data[49]. In fuzzy ELECTRE, linguistic preferences can easily be converted to fuzzy numbers[50]. In other words decision makers utilize fuzzy numbers instead of single values in the evaluation process of the ELECTRE[51].

The fuzzy set theory is ideally suited for handling these ambiguities encountered in solving MADM problems. Fuzzy logic – together with fuzzy arithmetic – could be used to develop procedures for treating vague and ambiguous information which is frequently expressed with linguistic variables and whose inaccuracy is not particularly due to the variability of the measures, but to the uncertainties inherent in the available information. Since [52] introduced fuzzy set theory, and [53] described the decision making method in fuzzy environments, an increasing number of studies have dealt with uncertain fuzzy problems by applying fuzzy set theory.

### 3.4 Fuzzy Set Theory:

Definition 1: Let  $X$  be a universal set [54]. The fuzzy set  $\tilde{A}$  in the universe of discourse  $X$  is characterized by the membership function  $\mu_{\tilde{A}}(x) \rightarrow [0,1]$ , where  $\mu_{\tilde{A}}(x), \forall x \in X$ , indicates the degree of membership of  $A$  to  $X$ .

Definition 2: A triangular fuzzy number  $\tilde{A}$  is described as the triplet  $(a^l, a^c, a^u)$ ,  $a^l \leq a^c \leq a^u$  [55]. The membership function  $\mu_{\tilde{A}}(x)$  is defined by

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x \leq a^l \\ \frac{x-a^l}{a^c-a^l}, & a^l < x < a^c \\ 1, & x = a^c \\ \frac{a^u-x}{a^u-a^c}, & a^c < x < a^u \\ 0, & x \geq a^u \end{cases} \quad (3.1)$$

Definition 3: For two fuzzy numbers  $\tilde{A}$  and  $\tilde{B}$ , the Hamming distance  $(\tilde{A}, \tilde{B})$  is defined by the following formula,

$$\int_R |\mu_{\tilde{A}}(x) - \mu_{\tilde{B}}(x)| \quad (3.2)$$

Where  $R$  is the set of real numbers [55].

Definition 4: A linguistic variable is a variable whose values are expressed in linguistic terms. The concept of a linguistic variable is very useful in dealing with situations, which are too complex or not well defined to be reasonably described in conventional quantitative expressions[55]. For example, “weight is a linguistic variable whose values can be defined as very low, low, medium, high, very high, etc. Fuzzy numbers are able to represent these linguistic values.

Definition 5: Assuming two fuzzy sets,  $\tilde{A}$  and  $\tilde{B}$ , their standard intersection,  $A \cap B$ , and their standard  $A \cup B$ , are defined for all  $x \in X$  as[54]:

$$(\tilde{A} \cap \tilde{B})(x) = \min[\tilde{A}(x), \tilde{B}(x)] \quad (3.3)$$

$$(\tilde{A} \cup \tilde{B})(x) = \max[\tilde{A}(x), \tilde{B}(x)]$$

Where *min* and *max* refer to minimum and maximum operators respectively.

Definition 6: Consider the two fuzzy sets,  $\tilde{A}$  and  $\tilde{B}$ , defined on the universal set  $X$  with a continuous membership function and  $\tilde{A} \cap \tilde{B} = \emptyset$ . Assume that  $x_m \in X$  is the point such that  $(\tilde{A} \cap \tilde{B})(x_m) \geq (\tilde{A} \cap \tilde{B})(x)$  for all  $x \in X$  and  $A(x_m) = B(x_m)$ , moreover  $x_m$  is between two mean values of  $\tilde{A}$  and  $\tilde{B}$ . Then, as suggested by [56], the operation max can be implemented as follows:

$$\max(A, B) = \begin{cases} (A \cap B)(z), & z < x_m \\ (A \cup B)(z), & z \geq x_m \end{cases} \quad (3.4)$$

where  $z \in X$ , and  $\cup$  and  $\cap$  denote the standard fuzzy intersection and union, respectively.

### 3.5 Proposed Frame Work:

The ELECTRE method is quick, operates with simple logic, and has the strength of being able to detect the presence of incomparability. It uses a systematic computational procedure, an advantage of which is an absence of strong axiomatic assumptions [57]. The fuzzy group ELECTRE method proposed in this study is an extension of the ELECTRE I method described next through a series of structured and successive steps depicted in Figure 3.1[58].

STEP1: Construct a fuzzy decision matrix: Assume that a decision making committee involves  $K$  decision makers (DMs)  $D_k (k = 1, 2, \dots, K)$ . The DMs are expected to determine the important weights of  $n$  attributes  $C_j (j = 1, 2, \dots, n)$  and the performance ratings of  $m$  possible alternatives  $A_i (i = 1, 2, \dots, m)$  on the attributes by means of linguistic variables. These linguistic variables will be transformed into positive triangular fuzzy numbers[58]. The fuzzy ratings of the alternatives and the fuzzy importance weights of the attributes for each DM are characterized by  $\tilde{X}_{ijk} = (X_{ijk}^l, X_{ijk}^c, X_{ijk}^u)$  and  $\tilde{w}_{jk} = (w_{jk}^l, w_{jk}^c, w_{jk}^u)$ , respectively ( $i = 1, 2, \dots, m, j = 1, 2, \dots, n, k = 1, 2, \dots, K$ ). For simplicity, we apply the average value method to get the consensus of the DMs' option. We also consider a voting power for each DMs,  $\zeta_k$ , as the proportion of the total power (where the total power is normalized to 1) according to some pre-specifies rule(s). In

contrast, the DMs can give equal weights where appropriate. Thus, the aggregated fuzzy ratings of the alternatives can be computed as follows:

$$\tilde{X}_{ij} = (X_{ij}^l, X_{ij}^c, X_{ij}^u), \quad i = 1, 2, \dots, m, \quad j = 1, 2, \dots, n. \quad (3.5)$$

Where,

$$X_{ij}^l = \frac{1}{K} \sum_{k=1}^K \zeta_k X_{ijk}^l, \quad X_{ij}^c = \frac{1}{K} \sum_{k=1}^K \zeta_k X_{ijk}^c, \quad X_{ij}^u = \frac{1}{K} \sum_{k=1}^K \zeta_k X_{ijk}^u \quad (3.6)$$

And  $\zeta_k$  is the voting power of the  $k$ th DM. Analogously, the aggregated fuzzy importance weights of the attributes can be calculated as

$$\tilde{w}_j = (w_j^l, w_j^c, w_j^u) \quad j = 1, 2, \dots, n \quad (3.7)$$

Where,

$$w_j^l = \frac{1}{K} \sum_{k=1}^K \zeta_k w_{jk}^l, \quad w_j^c = \frac{1}{K} \sum_{k=1}^K \zeta_k w_{jk}^c, \quad w_j^u = \frac{1}{K} \sum_{k=1}^K \zeta_k w_{jk}^u \quad (3.8)$$

Therefore the decision problem can expressed in matrix format as

$$\tilde{U} = \begin{bmatrix} \tilde{X}_{11} & \tilde{X}_{12} & \cdots & \tilde{X}_{1n} \\ \tilde{X}_{21} & \tilde{X}_{22} & \cdots & \tilde{X}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{X}_{m1} & \tilde{X}_{m2} & \cdots & \tilde{X}_{mn} \end{bmatrix}, \quad \tilde{w} = (\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n) \quad (3.9)$$

where  $\tilde{X}_{ij}$  is the fuzzy importance of the  $i$ th alternative with respect to the  $j$ th attribute and  $\tilde{w}_j$  is the fuzzy weight of the  $j$ th attribute.

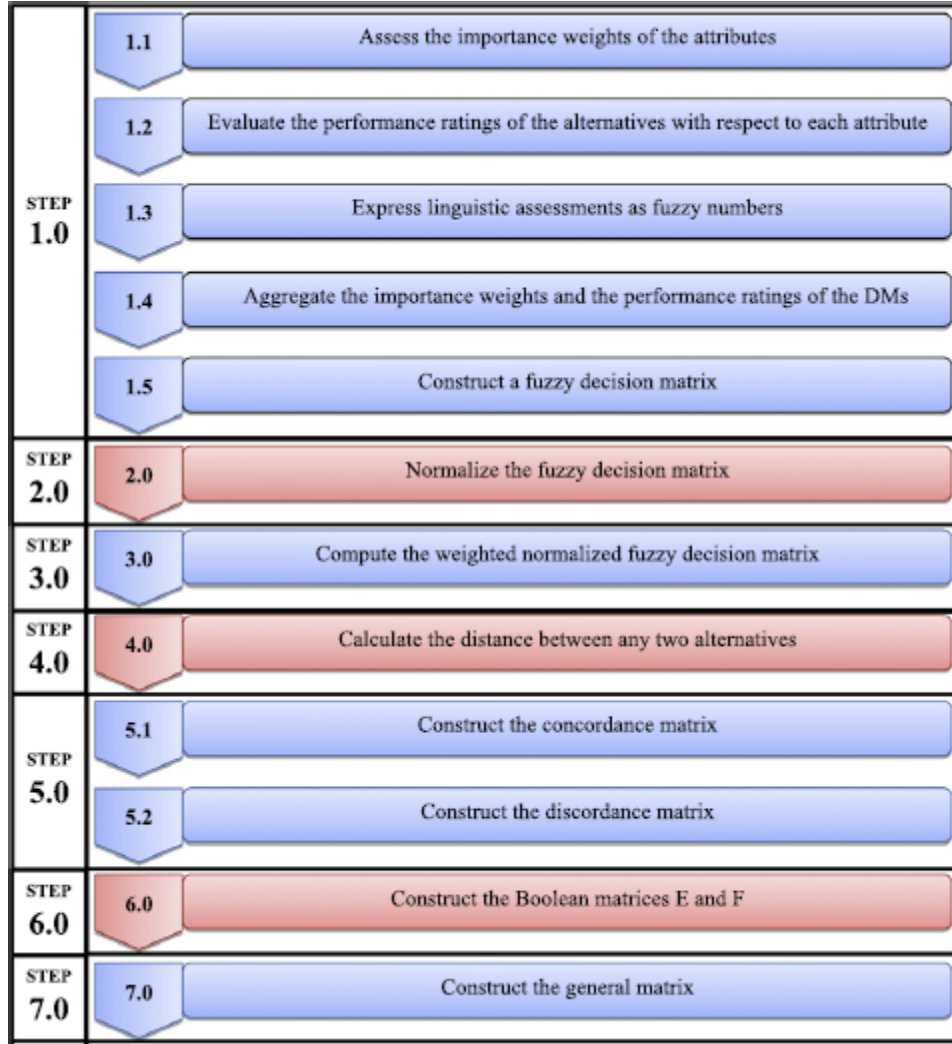


Figure 3.1: Proposed Frame work

Step 2: Normalize the fuzzy decision matrix: Depending on the Linguistic Variables and their corresponding triangular fuzzy numbers, normalization may not be necessary step[59]. In many cases, the fuzzy decision matrix is already normalized since the triangular fuzzy numbers belongs to the range  $[0, 1]$ . A linear scale normalization is applied next to ensure that all values in the decision matrix have homogeneous and comparable units. The normalized fuzzy decision matrix is constructed as follows:



$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \quad (3.10)$$

$$\tilde{r}_{ij} = (r_{ij}^l, r_{ij}^{\gamma}, r_{ij}^u) = \left( \frac{x_{ij}^l}{c_j^*}, \frac{x_{ij}^{\gamma}}{c_j^*}, \frac{x_{ij}^u}{c_j^*} \right), \quad i = 1, 2, \dots, m, \quad j \in B. \quad (3.11)$$

$$C_j^* = \max_i (X_{ij}^u), j \in B$$

Where  $B$  is the set of benefit attributes and

$$\tilde{r}_{ij} = (r_{ij}^l, r_{ij}^{\gamma}, r_{ij}^u) = \left( \frac{a_j^-}{x_{ij}^u}, \frac{a_j^-}{x_{ij}^{\gamma}}, \frac{a_j^-}{x_{ij}^l} \right), \quad i = 1, 2, \dots, m, \quad j \in C \quad (3.12)$$

$$a_j^- = \min_i (X_{ij}^l), j \in C$$

Where  $C$  is the set of cost attributes.

Step 3: Compute the weighted normalized fuzzy decision matrix: Assuming that the importance weights of the attributes are different, the weighted normalized fuzzy decision matrix is obtained by multiplying the importance weights of the attributes and the values in the normalized fuzzy decision matrix[58].

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n} \quad (3.13)$$

$$\tilde{v}_{ij} = (v_{ij}^l, v_{ij}^c, v_{ij}^u) = \tilde{w}_j(x) \tilde{r}_{ij} = (w_j^l r_{ij}^l, w_j^c r_{ij}^c, w_j^u r_{ij}^u)$$

Step 4: Calculate the distance between any two alternatives: The concordance and discordance matrices are constructed by utilizing the weighted normalized fuzzy decision

matrix and paired comparison among the alternatives. Considering two alternatives  $A_p$  and  $A_q$ , the concordance set is formed as  $J^C = \{j | \tilde{v}_{pj} \geq \tilde{v}_{qj}\}$  where  $J^C$  is the concordance coalition of the attributes in which  $A_p S A_q$ , and the discordance set is defined as  $J^D = \{j | \tilde{v}_{pj} \leq \tilde{v}_{qj}\}$  where  $J^D$  is the discordance coalition and it is against the assertion  $A_p S A_q$ . Note that  $S$  is the outranking relation and  $A_p S A_q$  means that " $A_p$  is at least as good as  $A_q$ " [58].

In order to compare any two alternatives,  $A_p$  and  $A_q$  with respect to each attribute, and to define the concordance and discordance sets, we specify the least upper bound of the alternatives,  $\max(\tilde{v}_{pj}, \tilde{v}_{qj})$  and then, the Hamming distance method is used which assumes that

$$\tilde{v}_{pj} \geq \tilde{v}_{qj} \Leftrightarrow d(\max(\tilde{v}_{pj}, \tilde{v}_{qj}), \tilde{v}_{qj}) \geq d(\max(\tilde{v}_{pj}, \tilde{v}_{qj}), \tilde{v}_{pj}) \quad (3.14)$$

$$\tilde{v}_{pj} \leq \tilde{v}_{qj} \Leftrightarrow d(\max(\tilde{v}_{pj}, \tilde{v}_{qj}), \tilde{v}_{qj}) \leq d(\max(\tilde{v}_{pj}, \tilde{v}_{qj}), \tilde{v}_{pj}) \quad (3.15)$$

Step 5: Construct the concordance and discordance matrices: The concordance and discordance matrices are obtained based on the Hamming distances. The following

concordance matrix is formed in which the elements are the fuzzy summation of the fuzzy importance weights for all the attributes in the concordance set[58].

$$\tilde{C} = \begin{bmatrix} - & \cdots & \tilde{C}_{1q} & \cdots & \tilde{C}_{1(m-1)} & \tilde{C}_{1m} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\ \tilde{C}_{p1} & \cdots & \tilde{C}_{pq} & \cdots & \tilde{C}_{p(m-1)} & \tilde{C}_{pm} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\ \tilde{C}_{m1} & \cdots & \tilde{C}_{mq} & \cdots & \tilde{C}_{m(m-1)} & - \end{bmatrix} \quad (3.16)$$

Where,

$$\tilde{C}_{pq} = (C_{pq}^l, C_{pq}^c, C_{pq}^u) = \sum_{j \in J^c} \tilde{w}_j = (\sum_{j \in J^c} \tilde{w}_j^l, \sum_{j \in J^c} \tilde{w}_j^c, \sum_{j \in J^c} \tilde{w}_j^u) \quad (3.17)$$

We then determine the concordance level as  $\bar{C} = (C^l, C^c, C^u)$ , where

$$C^l = \sum_{p=1}^m \sum_{q=1}^m \frac{C_{pq}^l}{m(m-1)}, C^c = \sum_{p=1}^m \sum_{q=1}^m \frac{C_{pq}^c}{m(m-1)},$$

$$\text{and } C^u = \sum_{p=1}^m \sum_{q=1}^m \frac{C_{pq}^u}{m(m-1)}.$$

The discordance matrix is structured as

$$D = \begin{bmatrix} - & \cdots & d_{1q} & \cdots & d_{1(m-1)} & d_{1m} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\ d_{p1} & \cdots & d_{pq} & \cdots & d_{p(m-1)} & d_{pm} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\ d_{m1} & \cdots & d_{mq} & \cdots & d_{m(m-1)} & - \end{bmatrix} \quad (3.18)$$

Where

$$d_{pq} = \frac{\max_{j \in J^D} |\tilde{v}_{pj} - \tilde{v}_{qj}|}{\max_j |\tilde{v}_{pj} - \tilde{v}_{qj}|} = \frac{\max_{j \in J^D} |d(\max(\tilde{v}_{pj}, \tilde{v}_{qj}), \tilde{v}_{qj})|}{\max_j |d(\max(\tilde{v}_{pj}, \tilde{v}_{qj}), \tilde{v}_{qj})|} \quad (3.19)$$

And the discordance level is defined as  $\bar{D} = \sum_{p=1}^m \sum_{q=1}^m \frac{d_{pq}}{m(m-1)}$

Step 6: Construct the Boolean Matrix  $E$  and  $F$ : The Boolean matrix  $E$  is determined by a minimum concordance level,  $\bar{C}$ , as follows:

$$E = \begin{bmatrix} - & \cdots & e_{1q} & \cdots & e_{1(m-1)} & e_{1m} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\ e_{1p} & \cdots & e_{pq} & \cdots & e_{p(m-1)} & e_{pm} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\ e_{m1} & \cdots & e_{mq} & \cdots & e_{m(m-1)} & - \end{bmatrix} \quad (3.20)$$

where

$$\begin{cases} \tilde{C}_{pq} \geq \bar{C} \Leftrightarrow e_{pq} = 1 \\ \tilde{C}_{pq} < \bar{C} \Leftrightarrow e_{pq} = 0 \end{cases} \quad (3.21)$$

and similarly, the Boolean matrix  $F$  is obtained based on the minimum discordance level,  $\bar{D}$ , as follows:

$$F = \begin{bmatrix} - & \cdots & f_{1q} & \cdots & f_{1(m-1)} & f_{1m} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\ f_{p1} & \cdots & f_{pq} & \cdots & f_{p(m-1)} & f_{pm} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\ f_{m1} & \cdots & f_{mq} & \cdots & f_{m(m-1)} & - \end{bmatrix} \quad (3.22)$$

where

$$\begin{cases} d_{pq} < \bar{D} \Leftrightarrow f_{pq} = 1 \\ d_{pq} \geq \bar{D} \Leftrightarrow f_{pq} = 0 \end{cases} \quad (3.23)$$

The elements in matrices  $E$  and  $F$  with the value of 1 indicate the dominance relation between alternatives.

Step7: Construct the General Matrix: By peer-to-peer multiplication of the elements of the matrices  $E$  and  $F$  [58], the general matrix  $G$  is constructed as

$$G = E \otimes F \quad (3.24)$$

## RESULTS AND COMPARISON

In this chapter, the performance evaluations of the proposed scheme are presented. The designed VHITS target network selection results are shown. This section shows the example to verify the validity and usability of proposed model.

### 4.1 Fuzzy ELECTRE Based Network Selection:

*Scenario1:* In this section we consider an example to verify the proposed model. There are four (target networks) alternatives A1, A2, A3, and A4 from which we need to select an optimum target network for the user. Three decision makers with the different voting power are used. The DM1 have 41% of the voting power ( $\zeta_1 = 0.41$ ) and DM2 have 34% of the voting power ( $\zeta_2 = 0.34$ ) and the DM3 have 25% of the voting power ( $\zeta_3 = 0.25$ ) respectively.

Table 4.1: Input Parameters:

	A1	A2	A3	A4
C1 RSS (dbm)	-87	-93	-83	-98
C2 Velocity (km/hr)	90	100	82	50
C3 cost	52	42	38	30

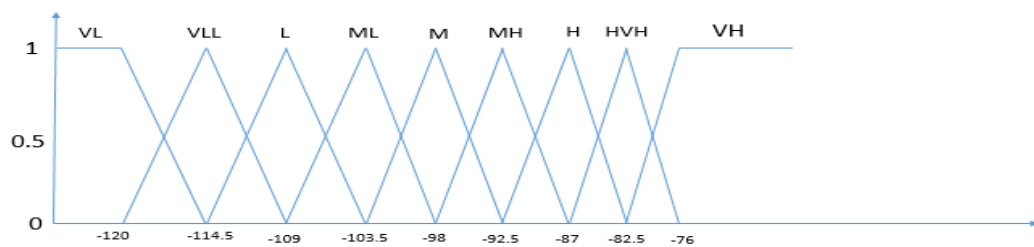


Figure 4.1 Membership Function for input variable RSS

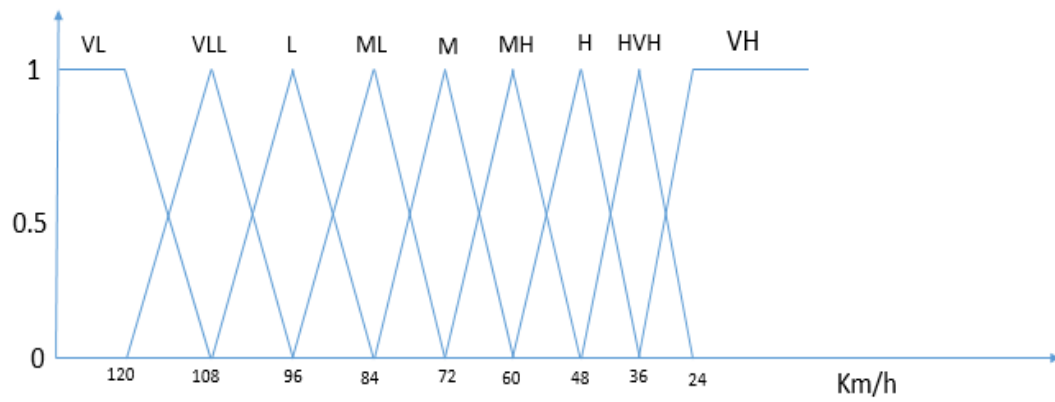


Figure 4.2 Membership Function for input variable velocity

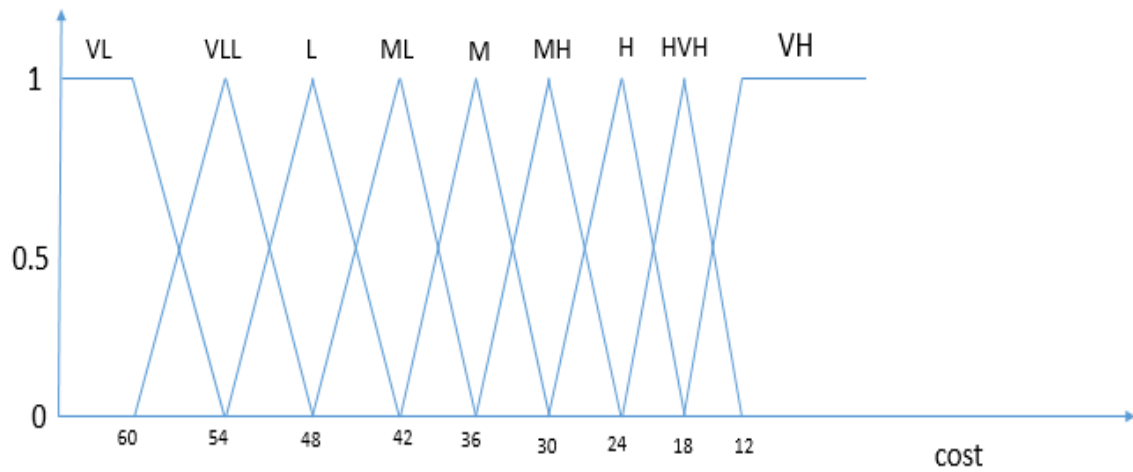


Figure 4.3 Membership Function for input variable cost

Table 4.2: Linguistic variables used to express important weights:

Linguistic Variables	Fuzzy Number
Very Low (VL)	(1,1,3)
Low (L)	(1,3,5)
Medium (M)	(3,5,7)
High (H)	(5,7,9)
Very High(VH)	(7,9,9)

Table 4.1 show the linguistic variables for expressing the important weights which represents the five linguistic variables Very Low (VL), Low (L), Medium (M), High (H), Very High(VH) used to characterize the important weights of attributes.

Table 4.3 Linguistic variables used to express performance ratings of networks:

Linguistic Variables	Fuzzy number
Very Low (VL)	(1,1,1.5)
Very Low to Low (VLL)	(1.5,2,2.5)
Low (L)	(2.5,3,3.5)
Medium Low (ML)	(3.5,4,4.5)
Medium (M)	(4.5,5,5.5)
Medium High (MH)	(5.5,6,6.5)
High (H)	(6.5,7,7.5)
High to Very High (HVH)	(7.5,8,8.5)
Very High (VH)	(8.5,9,9.5)

Similarly Table 4.2 shows the fuzzy number which represent the nine linguistic variables of Very Low (VL), Very Low to Low (VLL), Low (L), Medium Low



(ML), Medium (M), Medium High (MH), High (H), High to Very High (MVH), Very High (VH) which are used to characterize the performance rating of each network on each attributes.

Consider three attributes to assess each network (RSS (C1), Velocity (C2), and Cost (C3)). Table 4.3 shows the important weights of the attributes represented by linguistic variable.

Table 4.4: The importance weight of the attributes represented by linguistic variables:

Attributes	Decision Makers		
	DM1	DM2	DM3
RSS (C1)	H	M	M
Velocity (C2)	VH	H	H
Cost(C3)	M	L	VL

Table 4.5: The performance ratings of network represented by linguistic variables:

Attributes	Decision Makers	Alternatives			
		A1	A2	A3	A4
C1	DM1	H	MH	H	M
	DM2	H	MH	H	M
	DM3	H	H	MH	M
C2	DM1	L	VL	MH	H
	DM2	L	L	MH	H
	DM3	ML	L	MH	MH
C3	DM1	L	L	ML	MH
	DM2	VL	L	ML	MH
	DM3	VLL	ML	L	M

As shown in Table 4.5, the performance ratings of the target network A1, A2, A3, A4 were evaluated by three DMs using the linguistic variables defined in Table 4.3.

Table 4.6: The important weight and performance ratings represented by triangular fuzzy numbers:

Attribute s	Important Weights	Alternatives			
		A1	A2	A3	A4
C1	(1.27,1.94,2.61)	(2.17,2.33,2.50)	(1.92,2.08,2.50)	(2.08,2.25,2.41)	(1.50,1.67,1.83)
C2	(1.94,2.60,3)	(0.92,1.08,1.25)	(0.71,0.83,1.00)	(1.833,2.2,2.17)	(2.08,2.25,2.41)
C3	(0.606,1.106,1.77)	(0.58,0.69,0.86)	(0.75,0.92,1.08)	(1.08,1.25,1.41)	(1.75,1.92,2.08)

Table 4.6 is constructed using the Equations (3.6) and (3.8).

The normalized fuzzy decision matrix (Table 4.6) is obtained using Equation (3.11) for the benefits of the attributes.

Table 4.7: Normalized Fuzzy decision Matrix:

Attributes	Alternatives			
	A1	A2	A3	A4
C1	(0.86,0.93,1)	(0.76,0.83,0.90)	(0.83,0.9,0.96)	(0.6,0.66,0.73)
C2	(0.38,0.45,0.52)	(0.29,0.34,0.41)	(0.76,0.82,0.89)	(0.86,0.93,1)
C3	(0.27,0.33,0.41)	(0.36,0.44,0.51)	(0.52,0.6,0.68)	(0.84,0.92,1)

Table 4.8 shows the weighted normalized fuzzy decision matrix by substituting values in Equation (3.13)

Table 4.8: The weighted normalized fuzzy decision matrix:

Attributes	Alternatives			
	A1	A2	A3	A4
C1	(1.09,1.8,2.61)	(0.96,1.61,2.34)	(1.05,1.74,2.52)	(0.76,1.29,1.93)
C2	(0.74,1.16,1.55)	(0.57,0.89,1.24)	(1.47,2.15,2.68)	(1.67,2.42,3)
C3	(0.17,0.36,0.73)	(0.21,0.48,0.91)	(0.31,0.66,1.20)	(0.50,1.01,1.77)

The concordance Matrix is

Table 4.9: The Concordance Matrix:

	A1	A2	A3	A4
A1	-----	(3.21,4.50,5.61)	(1.27,1.94,2.60)	(1.27,1.94,2.60)
A2	(0.606,1.11,1.77)	-----	0	(1.27,1.94,2.60)
A3	(2.54,3.70,4.77)	(3.81,5.64,7.38)	-----	(1.27,1.94,2.60)
A4	(2.54,3.70,4.77)	(2.54,3.70,4.77)	(2.54,3.70,4.77)	-----

Table 4.10: Discordance Matrix:

	A1	A2	A3	A4
A1	-----	0.277	1	1
A2	1	-----	1	1
A3	0.084	0	-----	0.99
A4	0.49	0.714	1	-----

Table 4.11: The Boolean matrix E according to minimum Concordance level:

	A1	A2	A3	A4
A1	-----	1	0	0
A2	0	-----	0	0
A3	1	1	-----	0
A4	1	1	1	-----

Table 4.12: The Boolean matrix F according to minimum Discordance level:

	A1	A2	A3	A4
A1	_____	1	0	0
A2	0	_____	0	0
A3	1	1	_____	0
A4	1	1	1	_____

Table 4.13 The Global Matrix G:

	A1	A2	A3	A4
A1	_____	1	0	0
A2	0	_____	0	0
A3	1	1	_____	0
A4	1	1	1	_____

Table 4.14 Final Raking of alternatives:

Alternatives	Non-dominant alternatives	Final Ranking
A1	A2	3
A2	--	4
A3	A1,A2	2
A4	A1,A2,A3	1

The ranking of alternatives shows that:

- Network A1 dominates the network A2.
- Network A2 is dominated by the networks A1, A3, A4.
- Network A3 dominates the network A1 and A2.
- Network A4 dominates the network A1, A2, and A3.

*Scenario 2:* Assuming the end-user is leaving the home for work and starts walking towards the nearest bus stand while watching the same webcast. The distance between the WLAN and MS increases and the RSS become weaker the further the user walks away from his/her home. Handoff estimation is done and module will trigger the handoff, and execute the target network selection module to find out the best available network that can support the continuity and the quality of the currently utilized service.

Table 4.15 Input parameters when end-user is walking:

	A1	A2	A3	A4
C1 RSS (dbm)	-112.05	-125.40	-103.10	-98
C2 Velocity (m/s)	4	8	2	10
C2 Cost	52	42	38	30

Table 4.16 The Global Matrix when end-user walking:

	A1	A2	A3	A4
A1	_____	1	0	1
A2	0	_____	0	0
A3	1	1	_____	1
A4	0	1	1	_____

Table 4.17 Ranking of alternatives when end-user walking:

Alternatives	Non-Dominant Alternatives	Final Ranking
A1	A2	3
A2	_____	4
A3	A1,A2,A4	1
A4	A2,A3	2

On using the target network selection module for the end-user walking and the final ranking is obtained.

#### 4.2 ELECETRE based Network Selection:

In this scenario, using only ELECTRE method for network selection in heterogeneous wireless network. Fuzzy logic is not used in this scenario to check the results.

Table 4.18: The Boolean matrix E according to minimum Concordance level of ELECTRE:

	A1	A2	A3	A4
A1	-----	0	1	0
A2	1	-----	0	0
A3	1	1	-----	1
A4	1	0	1	-----

Table 4.19: The Boolean matrix F according to minimum Discordance level of ELECTRE:

	A1	A2	A3	A4
A1	-----	1	1	1
A2	0	-----	1	0
A3	1	0	-----	1
A4	0	0	1	-----

Table 4.20: The Global Matrix G for ELECTRE:

	A1	A2	A3	A4
A1	-----	0	1	0
A2	0	-----	0	0
A3	1	1	-----	1
A3	0	1	1	-----

Table 4.21: Final Raking of alternatives of ELECTRE:

Alternatives	Non-dominant alternatives	Ranking
A1	A3	3
A2	-----	4
A3	A1,A2,A4	1
A4	A2,A3	2

#### 4.3 Comparison of Results:

The Tables 4.18 shows the ranking of Fuzzy ELECTRE method and the ranking of the ELECTRE method. This comparison indicates that there is a change of ranking between the two methods. A problem with formulating the ELECTRE algorithm is the arbitrary selection of threshold values. These minimum values can significantly impact the outcome of the algorithm. In addition, the results of this method do not provide complete ranking for all the alternatives.

Table 4.22 Comparing of Results:

Alternatives	Fuzzy ELECTRE Ranking	ELECTRE Ranking
A1	3	3
A2	4	4
A3	2	1
A4	1	2

The difficulty of dealing with ambiguous and imprecise nature of linguistic assessment in traditional ELECTRE 1 method is overcome by the fuzzy ELECTRE1 method. It also integrates experts' judgement, experience and expertise in more flexible and realistic manner using the membership functions and the linguistic variables.



On adding fuzziness into the ELECTRE Methods gives greater stability and robustness, by allowing variations in the values of certain thresholds. With crisp values, a given change in criterion values, no matter how small, can result in creation or destruction of an outranking relationship and modifies the result significantly. With fuzzy criteria, this modification would certainly change the indices of the credibility and thus the result, but not in quite a terrible manner.

## CONCLUSION

This chapter summarizes the research work of handoff research.

### 5.1 Summary:

In a highly integrated ubiquitous heterogeneous wireless environment, the selection of a network that can fulfill end-users' service requests while keeping their overall satisfaction at a very high level is vital. A wrong selection can lead to undesirable conditions such as unsatisfied users, weak QoS, network congestions, dropped and/or blocked calls, and wastage of valuable network resources. The selection of these networks is performed during the handoff process when an MS switches its current PoA to a different network due to the degradation or complete loss of signal and/or deterioration of the provided QoS. The traditional schemes use only single metric for target selection. These schemes are not efficient enough to give good quality of service, so they do not take into consideration the traffic characteristics, user preferences, network conditions and other important system metrics.

The focus of this research work is on the design of a scheme that can perform the vertical handoffs efficiently in the heterogeneous wireless networks. The main objective of this scheme is to give the good QoS to the end-users.

The proposed module for VHITS Handoff Target Network selection utilizes fuzzy logic theory in addition to different ranking algorithms to select the best target network that can fulfill the end-user's preferences. According to this study Fuzzy ELECTRE method is the preferable method to achieve these targets.

## REFERENCE

- [1] M. Kassar, B. Kervella, and G. Pujolle, "An overview of vertical handover decision strategies in heterogeneous wireless networks," *Comput. Commun.*, vol. 31, no. 10, pp. 2607–2620, Jun. 2008.
- [2] I. F. Akyildiz, J. McNair, J. S. M. Ho, and H. Uzunalioglu, "Mobility management in next-generation wireless systems," *Proc. IEEE*, vol. 87, no. 8, pp. 1347–1384, 1999.
- [3] F. Zhu and J. McNair, "Multiservice Vertical Handoff Decision Algorithms," *EURASIP J. Wirel. Commun. Netw.*, vol. 2006, no. 1, pp. 1–13, Jul. 2006.
- [4] J.-M. Kang, J. Strassner, S. Seo, and J. W.-K. Hong, "Autonomic personalized handover decisions for mobile services in heterogeneous wireless networks," *Comput. Networks*, vol. 55, no. 7, pp. 1520–1532, May 2011.
- [5] N. Nasser, A. Hasswa, and H. Hassanein, "Handoffs in fourth generation heterogeneous networks," *IEEE Commun. Mag.*, vol. 44, no. 10, pp. 96–103, Oct. 2006.
- [6] J. H. R. H. F. V. Nishith D. Tripathi, "Handoff in Cellular Systems."
- [7] I. F. Akyildiz and W. Wang, "A dynamic location management scheme for next-generation multitier PCS systems," *IEEE Trans. Wirel. Commun.*, vol. 1, no. 1, pp. 178–189, 2002.
- [8] N. Mani and Y. A. Cekericioglu, "A Traveling Distance Prediction Based Method to Minimize Unnecessary Handovers from Cellular Networks to WLANs," *IEEE Commun. Lett.*, vol. 12, no. 1, pp. 14–16, Jan. 2008.
- [9] A. H. Zahran, B. Liang, and A. Saleh, "Signal threshold adaptation for vertical handoff in heterogeneous wireless networks," *Mob. Networks Appl.*, vol. 11, no. 4, pp. 625–640, May 2006.
- [10] S. Mohanty and I. F. Akyildiz, "A Cross-Layer (Layer 2 + 3) Handoff Management Protocol for Next-Generation Wireless Systems," *IEEE Trans. Mob. Comput.*, vol. 5, no. 10, pp. 1347–1360, Oct. 2006.
- [11] M. D. Austin and G. L. Stuber, "Velocity adaptive handoff algorithms for microcellular systems," in *Proceedings of 2nd IEEE International Conference on Universal Personal Communications*, 1993, vol. 2, pp. 793–797.
- [12] L. Hua, M. H. Kabir, and T. Sato, "Velocity adaptive vertical handoff on multi-frequency system," in *2009 IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communications*, 2009, pp. 773–777.

- [13] Young-il Kim, Kyung-Jun Lee, and Yong-Oak Chin, "Analysis of multi-level threshold handoff algorithm," in *Proceedings of GLOBECOM'96. 1996 IEEE Global Telecommunications Conference*, 1996, vol. 2, pp. 1141–1145.
- [14] M. D. Austin and G. L. Stuber, "Direction biased handoff algorithms for urban microcells," in *Proceedings of IEEE Vehicular Technology Conference (VTC)*, 1994, pp. 101–105.
- [15] Li Zheng, Wang Yu, and Wu Weiling, "Position location and direction assisted handoff algorithm in DWCS," in *2004 IEEE 15th International Symposium on Personal, Indoor and Mobile Radio Communications (IEEE Cat. No.04TH8754)*, 2004, vol. 1, pp. 663–666.
- [16] N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, "An adaptive direction biased fuzzy handoff algorithm with unified handoff candidate selection criterion," in *VTC '98. 48th IEEE Vehicular Technology Conference. Pathway to Global Wireless Revolution (Cat. No.98CH36151)*, 1998, vol. 1, pp. 127–131.
- [17] R. D. Yates, "Evaluation of a minimum power handoff algorithm," in *Proceedings of 6th International Symposium on Personal, Indoor and Mobile Radio Communications*, 1995, vol. 2, pp. 814–818.
- [18] Q.-T. Nguyen-Vuong, N. Agoulmine, and Y. Ghamri-Doudane, "A user-centric and context-aware solution to interface management and access network selection in heterogeneous wireless environments," *Comput. Networks*, vol. 52, no. 18, pp. 3358–3372, Dec. 2008.
- [19] A. Helmy, B. Jennings, L. Murphy, and T. Pfeifer, Eds., *Autonomic Management of Mobile Multimedia Services*, vol. 4267. Berlin, Heidelberg: Springer Berlin Heidelberg, 2006.
- [20] A. Hasswa, N. Nasser, and H. Hassanein, "Generic vertical handoff decision function for heterogeneous wireless networks," in *Second IFIP International Conference on Wireless and Optical Communications Networks, 2005. WOCN 2005.*, 2005, pp. 239–243.
- [21] A. Calvagna and G. Di Modica, "A user-centric analysis of vertical handovers," in *Proceedings of the 2nd ACM international workshop on Wireless mobile applications and services on WLAN hotspots - WMASH '04*, 2004, p. 137.
- [22] T. Ahmed, K. Kyamakya, and M. Ludwig, "Design and implementation of a context-aware decision algorithm for heterogeneous networks," in *Proceedings of the 2006 ACM symposium on Applied computing - SAC '06*, 2006, p. 1134.
- [23] P. TalebiFard and V. C. . Leung, "A dynamic context-aware access network selection for handover in heterogeneous network environments," in *2011 IEEE*

*Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, 2011, pp. 385–390.

- [24] Q. Wei, K. Farkas, C. Prehofer, P. Mendes, and B. Plattner, “Context-aware handover using active network technology,” *Comput. Networks*, vol. 50, no. 15, pp. 2855–2872, Oct. 2006.
- [25] M. Xiong, J. Cao, and J. Zhang, “Context-Aware Mechanism for IEEE 802.21 Media Independent Handover,” in *2011 Proceedings of 20th International Conference on Computer Communications and Networks (ICCCN)*, 2011, pp. 1–6.
- [26] M. Zekri, B. Jouaber, and D. Zeghlache, “Context aware vertical handover decision making in heterogeneous wireless networks,” in *IEEE Local Computer Network Conference*, 2010, pp. 764–768.
- [27] R. Tawil, G. Pujolle, and O. Salazar, “A Vertical Handoff Decision Scheme in Heterogeneous Wireless Systems,” in *VTC Spring 2008 - IEEE Vehicular Technology Conference*, 2008, pp. 2626–2630.
- [28] E. Stevens-Navarro and V. W. S. Wong, “An MDP-Based Vertical Handoff Decision Algorithm for Heterogeneous Wireless Networks,” *IEEE Trans. Veh. Technol.*, vol. 57, no. 2, pp. 1243–1254, Mar. 2008.
- [29] K. Sriram and N. Golmie, “Vertical Handoff Decision Algorithms for Providing Optimized Performance in Heterogeneous Wireless Networks,” *IEEE Trans. Veh. Technol.*, vol. 58, no. 2, pp. 865–881, Feb. 2009.
- [30] 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*, 2006, vol. 2, pp. 947–951.
- [31] J. D. Martinez-Morales, U. Pineda-Rico, and E. Stevens-Navarro, “Performance comparison between MADM algorithms for vertical handoff in 4G networks,” in *2010 7th International Conference on Electrical Engineering Computing Science and Automatic Control*, 2010, pp. 309–314.
- [32] J. R. Gallardo-Medina, U. Pineda-Rico, and E. Stevens-Navarro, “VIKOR method for vertical handoff decision in beyond 3G wireless networks,” in *2009 6th International Conference on Electrical Engineering, Computing Science and Automatic Control (CCE)*, 2009, pp. 1–5.
- [33] P. Nguyen Tran and N. Boukhatem, “Comparison of MADM decision algorithms for interface selection in heterogeneous wireless networks,” in *2008 16th International Conference on Software, Telecommunications and Computer Networks*, 2008, pp. 119–124.

- [34] A. Ismail and Byeong-hee Roh, "Adaptive Handovers in heterogeneous networks using fuzzy MADM." pp. 99–104, 2011.
- [35] K. Taniuchi, Y. Ohba, V. Fajardo, S. Das, M. Taail, A. Dutta, D. Baker, M. Yajnik, and D. Famolari, "IEEE 802.21: Media independent handover: Features, applicability, and realization," *IEEE Commun. Mag.*, vol. 47, no. 1, pp. 112–120, Jan. 2009.
- [36] T. Özcan, N. Çelebi, and Ş. Esnaf, "Comparative analysis of multi-criteria decision making methodologies and implementation of a warehouse location selection problem," *Expert Syst. Appl.*, vol. 38, no. 8, pp. 9773–9779, Aug. 2011.
- [37] F. Bari and V. Leung, "Application of ELECTRE to Network Selection in A Heterogeneous Wireless Network Environment," in *2007 IEEE Wireless Communications and Networking Conference*, 2007, pp. 3810–3815.
- [38] F. Bari and V. C. M. Leung, "Use of non-monotonic utility in multi-attribute network selection," in *2007 Wireless Telecommunications Symposium*, 2007, pp. 1–8.
- [39] 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*, 2011, pp. 1–5.
- [40] A. Sgora, D. D. Vergados, and P. Chatzimisios, "An access network selection algorithm for heterogeneous wireless environments," in *The IEEE symposium on Computers and Communications*, 2010, pp. 890–892.
- [41] S. Liu, S. Pan, Z. Mi, Q. Meng, and M. Xu, "A Simple Additive Weighting Vertical Handoff Algorithm Based on SINR and AHP for Heterogeneous Wireless Networks," in *2010 International Conference on Intelligent Computation Technology and Automation*, 2010, vol. 1, pp. 347–350.
- [42] S. Opricovic and G.-H. Tzeng, "Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS," *Eur. J. Oper. Res.*, vol. 156, no. 2, pp. 445–455, 2004.
- [43] Wenhui Zhang, "Handover decision using fuzzy MADM in heterogeneous networks," in *2004 IEEE Wireless Communications and Networking Conference (IEEE Cat. No.04TH8733)*, 2004, vol. 2, pp. 653–658.
- [44] M. Sevkli, "An application of the fuzzy ELECTRE method for supplier selection," *Int. J. Prod. Res.*, vol. 48, no. 12, pp. 3393–3405, Jun. 2010.

- [45] A. S. Milani, A. Shanian, and C. El-Lahham, "Using different ELECTRE methods in strategic planning in the presence of human behavioral resistance.," *J. Appl. Math. Decis. Sci.*, vol. 2006, p. Article ID 10936, 19 p.
- [46] B. Roy and J.-M. Martel, "Analyse de la signifiante de diverses procédures d'agrégation multicritère," 2006.
- [47] X. Wang and E. Triantaphyllou, "Ranking irregularities when evaluating alternatives by using some ELECTRE methods," *Omega*, vol. 36, no. 1, pp. 45–63, 2008.
- [48] F. Asghari, A. A. Amidian, J. Muhammadi, and H. Rabiee, "A Fuzzy ELECTRE Approach for Evaluating Mobile Payment Business Models," in *2010 International Conference on Management of e-Commerce and e-Government*, 2010, pp. 351–355.
- [49] B. Vahdani, A. H. K. Jabbari, V. Roshanaei, and M. Zandieh, "Extension of the ELECTRE method for decision-making problems with interval weights and data," *Int. J. Adv. Manuf. Technol.*, vol. 50, no. 5–8, pp. 793–800, Feb. 2010.
- [50] T. Kaya and C. Kahraman, "An integrated fuzzy AHP–ELECTRE methodology for environmental impact assessment," *Expert Syst. Appl.*, vol. 38, no. 7, pp. 8553–8562, Jul. 2011.
- [51] M.-C. Wu and T.-Y. Chen, "The ELECTRE multicriteria analysis approach based on Atanassov's intuitionistic fuzzy sets," *Expert Syst. Appl.*, vol. 38, no. 10, pp. 12318–12327, Sep. 2011.
- [52] L. A. Zadeh, "Fuzzy sets," *Inf. Control*, vol. 8, no. 3, pp. 338–353, Jun. 1965.
- [53] R. E. Bellman and L. A. Zadeh, "Decision-Making in a Fuzzy Environment," *Manage. Sci.*, vol. 17, no. 4, p. B–141–B–164, Dec. 1970.
- [54] D. DUBOIS and H. PRADE, "Operations on fuzzy numbers," *Int. J. Syst. Sci.*, vol. 9, no. 6, pp. 613–626, Jun. 1978.
- [55] K. GEORGE J. and Y. BO, "FUZZY SETS AND FUZZY LOGIC, THEORY AND APPLICATIONS," -. 02-Mar-2008.
- [56] C.-H. Chiu and W.-J. Wang, "A simple computation of MIN and MAX operations for fuzzy numbers," *Fuzzy Sets Syst.*, vol. 126, no. 2, pp. 273–276, Mar. 2002.
- [57] A. Shanian and O. Savadogo, "A material selection model based on the concept of multiple attribute decision making," *Mater. Des.*, vol. 27, no. 4, pp. 329–337, Jan. 2006.

- [58] A. Hatami-Marbini, M. Tavana, M. Moradi, and F. Kangi, "A fuzzy group Electre method for safety and health assessment in hazardous waste recycling facilities," *Saf. Sci.*, vol. 51, no. 1, pp. 414–426, Jan. 2013.
- [59] F. Kaleem, "VHITS: Vertical Handoff Initiation and Target Selection in a Heterogeneous Wireless Network," *FIU Electronic Theses and Dissertations*. 2012.



## Appendix

Matlab code:

```
function main()
[U, w] = GenFuzzyInputData();
R = NormalizeData(U);
V = NormalizeWeighted(w,R);
[C, D] = ConDiscMatrix(V, w);
[E, F] = FindEandF(C,D);
G = E.*F;
end

function [U, w] = GenFuzzyInputData() %For fuzzy input data%
% Params
N_dm = 3;

% Define linguistic variables
VL = {1 1 1.5};
VLL = {1.5 2 2.5};
L = {2.5 3 3.5};
ML = {3.5 4 4.5};
M = {4.5 5 5.5};
MH = {5.5 6 6.5};
H = {6.5 7 7.5};
HVH = {7.5 8 8.5};
VH = {8.5 9 9.5};

% Enter performance ratings
PR = [H MH H H;
      H MH H M;
      H H MH M;
      L VL MH H;
      L L MH H;
      ML L MH MH;
      L L ML MH;
      VL L ML MH;
      VLL VL L M];

x_ij_l = zeros(N_alt,N_attr);
x_ij_g = x_ij_l;
x_ij_u = x_ij_l;
for n = 1:N_attr
    for k = 1:N_alt
        l=0; g=0; u=0;
        for x = 1:N_dm
```

```

        idx_col = (k-1)*3+1;
        idx_row = (n-1)*N_dm+x;
        l = l + zeta_k(x)*PR{idx_row,idx_col};
        g = g + zeta_k(x)*PR{idx_row,idx_col+1};
        u = u + zeta_k(x)*PR{idx_row,idx_col+2};
    end
    x_ij_l(k,n) = 1/N_dm*l;
    x_ij_g(k,n) = 1/N_dm*g;
    x_ij_u(k,n) = 1/N_dm*u;
end
end
U = {x_ij_l, x_ij_g, x_ij_u};

% Define linguistic variables for weights
VLw = {1 1 3};
Lw = {1 3 5};
Mw = {3 5 7};
Hw = {5 7 9};
VHw = {7 9 9};

% Weights of attributes
WA = [Hw Mw Mw;
      VHw Hw Hw;
      Mw Lw VLw];

w_j_l = zeros(N_attr,1);
w_j_g = w_j_l;
w_j_u = w_j_l;
for n = 1:N_attr
    l=0; g=0; u=0;
    for x = 1:N_dm
        idx_col = (x-1)*3+1;
        l = l + zeta_k(x)*WA{n,idx_col};
        g = g + zeta_k(x)*WA{n,idx_col+1};
        u = u + zeta_k(x)*WA{n,idx_col+2};
    end
    w_j_l(n) = 1/N_dm*l;
    w_j_g(n) = 1/N_dm*g;
    w_j_u(n) = 1/N_dm*u;
end
w = {w_j_l, w_j_g, w_j_u};

end
Normalizing the data:

```

```

function R = NormalizeData(U)
x_ij_1 = U{1};
x_ij_g = U{2};
x_ij_u = U{3};
C_j = max(x_ij_u,[],1);
r_ij_1 = x_ij_1./repmat(C_j,size(x_ij_1,1),1);
r_ij_g = x_ij_g./repmat(C_j,size(x_ij_1,1),1);
r_ij_u = x_ij_u./repmat(C_j,size(x_ij_1,1),1);
R = {r_ij_1, r_ij_g, r_ij_u};
end

```

Weighted Normalizing:

```

function V = NormalizeWeighted(w,R)
r_ij_1 = R{1};
r_ij_g = R{2};
r_ij_u = R{3};
w_j_1 = w{1}';
w_j_g = w{2}';
w_j_u = w{3}';
v_ij_1 = repmat(w_j_1,size(r_ij_1,1),1).*r_ij_1;
v_ij_g = repmat(w_j_g,size(r_ij_g,1),1).*r_ij_g;
v_ij_u = repmat(w_j_u,size(r_ij_u,1),1).*r_ij_u;
V = {v_ij_1, v_ij_g, v_ij_u};
end

```

Calculating concordance and Discordance Matrix:

```

function [C, D] = ConDiscMatrix(V, w)
C = cell(3,1);
C{1} = zeros(size(V{1},1));
C{2} = zeros(size(V{2},1));
C{3} = zeros(size(V{3},1));
D = C{1};
for p = 1:size(C{1},1)
    for q = 1:size(C{1},2)
        if(p~=q)
            Jd = [];
            d_vpj_vqj = zeros(1,size(V{1},2));
            for j = 1:size(V{1},2)
                v_pj = [V{1}(p,j) V{2}(p,j) V{3}(p,j)];
                v_qj = [V{1}(q,j) V{2}(q,j) V{3}(q,j)];
                d_vpj_vqj(j) = HammingDistFuzzy(v_pj, v_qj);
                d_vqj_vpj = HammingDistFuzzy(v_qj, v_pj);
                if(d_vpj_vqj >= d_vqj_vpj)
                    C{1}(p,q) = C{1}(p,q) + w{1}(j);
                end
            end
        end
    end
end

```

```

        C{2}(p,q) = C{2}(p,q) + w{2}(j);
        C{3}(p,q) = C{3}(p,q) + w{3}(j);
    end
    if(HammingDistFuzzy(v_pj, v_qj) <= HammingDistFuzzy(v_qj, v_pj))
        Jd = [Jd j];
    end
end
end
if(~isempty(max(d_vpj_vqj(Jd))/max(d_vpj_vqj)))
    D(p,q) = max(d_vpj_vqj(Jd))/max(d_vpj_vqj);
end
end
end
end
end
end

```

Finding E and F matrix:

```

function [E, F] = FindEandF(C,D)
m = size(C{1},1);
cl = sum(sum(C{1}))/m*(m-1);
cg = sum(sum(C{2}))/m*(m-1);
cu = sum(sum(C{3}))/m*(m-1);
C_bar = [cl cg cu];
D_bar = sum(sum(D))/m*(m-1);
E = zeros(m);
F = zeros(m);
for p = 1:m
    for q = 1:m
        if(p~=q)
            c_pq = [C{1}(p,q) C{2}(p,q) C{3}(p,q)];
            if(HammingDistFuzzy(c_pq,C_bar) >= HammingDistFuzzy(C_bar,c_pq))
                E(p,q) = 1;
            end
            if(D(p,q)<D_bar)
                F(p,q) = 1;
            end
        end
    end
end
end
end
end
end

```