Development of UGV Communication System using Wi-Fi Network Hopping technique

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Declaration

I certify that this research work titled "*Development of UGV Communication System using Wi-Fi Network Hopping technique"* is my work. It has not been presented elsewhere for assessment. The material that has been used from other sources has been properly acknowledged/referred.

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This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical, and spelling mistakes. The thesis is also according to the format given by the university.

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Copyright Statement

Acknowledgments

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Abstract

With the advancement in wireless technologies for better quality of service and connectivity, seamless roaming capability for unmanned ground vehicle (UGV) have been the focus of research. To provide mobility features in a network, handoff management techniques are utilized based on the multiple network parameters and decision criteria. The research describes recently used methodologies for handoff involving single to multiple network parameters. The focus of the research is utilizing fuzzy technique for order performance by similarity to ideal solution (F-TOPSIS) based handoff decision making algorithm with six parametric weights i.e., received signal strength indicator (RSSI), bandwidth, signal to interference & noise ratio (SINR), network delay, data loss, and bit error rate, calculation using fuzzy analytical hierarchal process (FAHP) involving three traffic classes i.e., video, control, and background. Three decision metrices for network, mobile node, and user preference, are used in decision making algorithm by evaluating performance coefficient of available networks based on their respective distance from best and worst ideal solutions. Handoff criteria-I and II based on difference of performance value and its percentage respectively are proposed to manage handoff decision making process. Performance analysis of handoff criteria-I & II is done based on different environmental conditions with varying threshold and best performance values to reduce the number of unnecessary handoffs and handoff response time. The network classification based on performance value from proposed technique is compared to traditional TOPSIS and suitable threshold value reduces the number of unnecessary handoffs and response time without affecting the handoff performance.

Keywords: *Handoff, Handoff management, Multiple parametric weights, Fuzzy TOPSIS, FAHP, Handoff performance analysis*

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Muhammad Wajid Khan, Umar S. Khan, Muhammad Mubasher Saleem, and Nasir Rashid. 2022. “Multi-criteria Handoff Decision making Algorithm for Seamless Mobility in Heterogeneous Wireless Networks”

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List Abbreviations

AP	Access Point
BS	Base Station
FAHP	Fuzzy Analytical Hierarchal Process
FGM	Fuzzy Geometric Mean
MAHO	Mobile Assisted Handoff
MCDM	Multi-Criteria Decision Making
NCHO	Network Controlled Handoff
RATs	Radio Access Technologies
RSSI	Received Signal Strength Indicator
SDN	Software Defined Networks
SINR	Signal to Interference & Noise Ratio
TOPSIS	Technique for Order Performance by Similarity to Ideal Solution
UGV	Unmanned Ground Vehicle
VHO	Vertical Handoff

Chapter 1: Introduction

1.1 Overview

In this progressive age of digitization, mobile robots are being utilized for most of the tasks related to surveillance, warehouse management, structural adversary management etc. Mobile robots such as unmanned ground vehicle (UGV) have proved themselves in terms of mobility, control, and stability. UGVs are popular for their autonomous control and task acquisition in restrictive environmental conditions. UGV require seamless mobility and a stable connection for mobility and control. The working effectiveness of UGV is highly dependent on reliable communication network and efficient mobility management. Different radio access technologies (RATs) are being utilized to provide seamless mobility and stable communication services i.e., Wireless Local Area Network (WLAN), 3G, 4G Networks, etc. While operating UGV switch from one network to another which is referred as Handoff. The current research discusses the handoff decision making for seamless mobility management of UGV in different RATs.

The prominent research areas relevant to the topic are:

1. Mobile Communication
2. Vehicular Communication
3. Wireless Communication & Networking
4. Optimization of Handoff Management
5. Emerging Communication Technology & Standards

This chapter includes overview of different types of UGV and RATs, Handoff process and types, mobility management, handoff decision protocols, challenges in seamless mobility and research contribution.

1.2 Unmanned Ground Vehicle (UGV)

Unmanned ground vehicle are mobile robots that perform tasks in hazardous or fetal environmental conditions while maintaining contact with the ground. Normally, UGVs are embedded with sensors to collect information, end effectors for performing multiple tasks, and control system for decision making. UGVs are operated in a communication network to send collected information and receive control signals. The degree of control further classifies UGVs into following categories:

1. Teleoperated UGV
2. Semi-Autonomous UGV
3. Platform-centric Autonomous UGV
4. Network-centric Autonomous UGV

The communication network for teleoperated UGV under different radio access networks are discussed.

1.3 Radio Access Technologies (RATs)

UGV utilize its communication network for data transmission and control. The communication network can utilize different radio access technologies for wireless communication which include WLAN, 3G, 4G etc. The network formed by utilizing these RATs are divided into homogenous and heterogeneous wireless networks. The wireless networks formed by same type of RAT is homogenous wireless network while utilizing several types of RATs make heterogeneous wireless network. The heterogeneous wireless networks provide a variety of data rates, and services. These services are utilized by user or mobile node.

The fundamental architecture of these RATs in heterogeneous wireless network is different which makes mobility management a major concern for seamless connectivity.

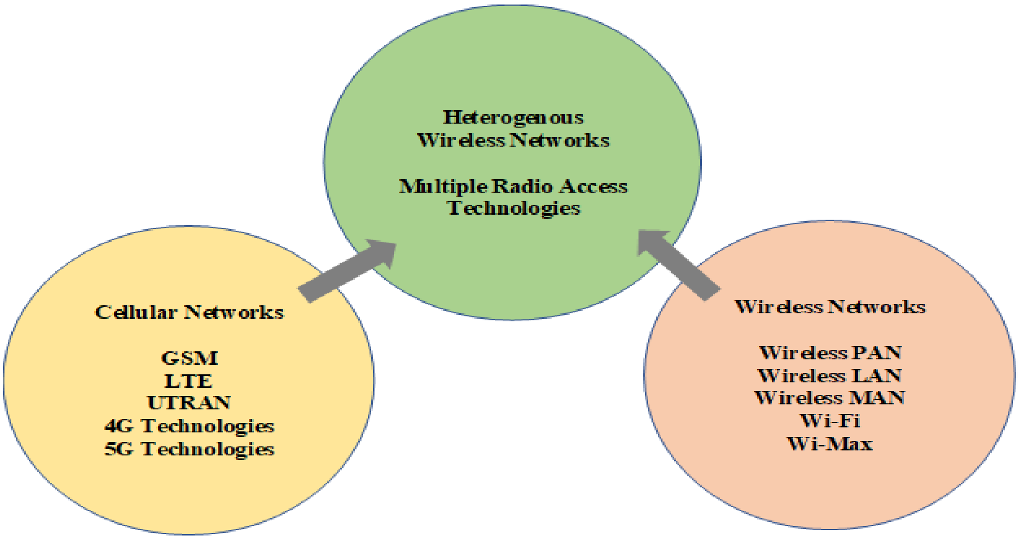

Figure 1.1 Heterogeneous Wireless Networks

1.4 Handoff

In a wireless network, user or mobile node may jump from one access point to another which is refer to as handoff. The handoff may occur due to insufficient signal strength, loss of connection, inadequate quality of service (QoS), high network load etc.

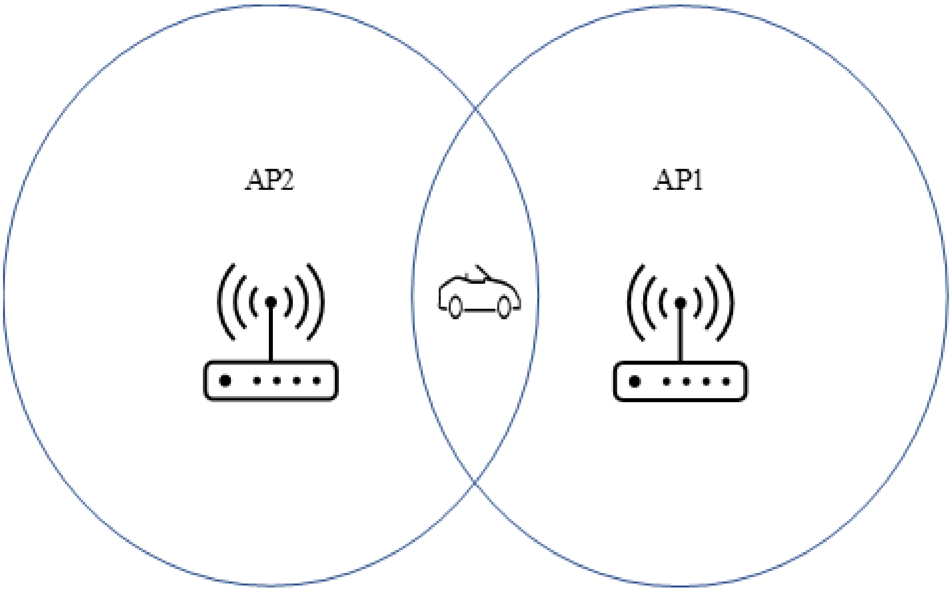

Figure 1.2 Handoff between two access points (AP)

1.4.1 Handoff Types

The following section discuses several types of handoffs based on handoff execution process, speed of mobile node and type of network [1].

1.4.1.1 Soft & Hard Handoff

Soft handoff is known as make before break i.e., mobile node makes new connection first before disconnecting with previous base station. Code division multiple access (CDMA) is utilized by the system for soft handoff using same frequency band.

Hard handoff follows break before make technique in which mobile node break its previous connection before making a new one. Time division multiple access (TDMA) and frequency division multiple access (FDMA) system are utilized in hard handoff i.e., global system for mobile communication (GSM) general packet radio service (GPRS).

1.4.1.2 Microcellular & Multilayer Handoff

Microcellular handoff occurs in systems with base station having small cell radii. It is utilized in high populated environment like small buildings and streets. Multilayer design is utilized for decreasing the number of handoffs and increasing the number of users. Macrocell oversee microcells and each user is connected to the layer according to its speed. High speed users are assigned to macrocells and low speed or stationary users are assigned to microcells, which in turn reduces number of handoffs.

1.4.1.3 Horizontal & Vertical Handoff

Horizontal handoff occurs in homogenous wireless networks i.e., having same type of networks or RATs, while vertical handoff occurs in heterogeneous wireless networks i.e., with different type of network.

1.4.2 Handoff Process

The overall handoff process is divided into three main steps namely, handoff initiation, handoff decision, and handoff execution [2].

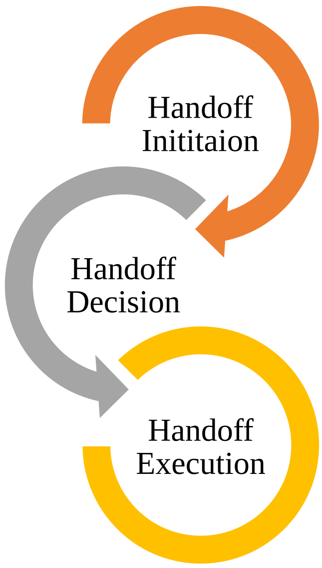

Figure 1.3 Basic Handoff Process

1.4.2.1 Handoff Initiation

The handoff initiation step involves the collection of necessary information regarding the chosen parameters e.g., received signal strength identifier (RSSI), signal to interference & noise ratio (SINR), packet loss (PL), for handoff decision in second step [3]. These network parameters can be categorized into three domains:

1. Network: include network parameters i.e., RSSI, bandwidth, network load.
2. Mobile Terminal: include velocity, power consumption.
3. User: cost, applications.

1.4.2.2 Handoff Decision

Handoff decision making is done by utilizing the information received in handoff initiation phase for decision making algorithm. The algorithm decides the preferability of handoff by evaluating each available network. The evaluation is quantized in terms of performance value to rank each network.

1.4.2.3 Handoff Execution

The last step includes the breaking of connection with previous base station (BS_p) and making new connection with the next base station (BP_n). The handoff execution is done by handoff initiation criteria based on the performance value calculated in previous step.

1.5 Mobility Management

In collaboration with different radio access technology (RAT), there will be situations where mobile node will move from one RAT to another. In those scenarios, user require a management system which can guide its connectivity without any drop in QoS. The mobility management provide such a system for user or mobile node to effectively roam in heterogeneous wireless networks.

Mobility management should be able to provide quality of service to the user i.e., user's base station accesses the network either if it is moving, user should be able to receive connectivity with other base stations even if it is freely roaming, and user should get its services irrespective of the user's location in the wireless network without leaving the coverage area.

Mobility management is further classified into two categories i.e., Location management and Handoff management [4]. Location management is mostly related to tracking or positioning of mobile node while handoff management discusses switching of access points in wireless networks.

1.5.1 Location Management

Location management is the technique to identify the position of the mobile node and its connectivity with respective base station. The identification of base station provides the information about the cell in which mobile node is roaming. The mobile node sends its location information to the system i.e., location update and then the system determine the location of mobile node by establishing communication link i.e., call delivery.

1.5.2 Handoff Management

Handoff management involves the switching of mobile node from one network terminal to another. When a network terminal is unable to provide QoS in terms of its throughput, mobility, and seamless connection then handoff is initiated. Following are the handoff decision protocols.

1.5.2.1 Network Controlled Handoff (NCHO)

In network-controlled handoff environment, network is responsible for the initiating and controlling the handoff process. It is adopted in systems such as telephone stations where mobile telephone switching center manages the RSS measurement and handoff decision making. Since all the load is on network, handoff may take considerable time to achieve.

1.5.2.2 Mobile Assisted Handoff (MAHO)

In mobile-assisted handoff, network load is reduced by utilizing mobile node for RSS measurement and handoff decision making. Network receives signals from mobile node and execute handoff accordingly. This type of system is used in global systems for mobile communication (GSM) for making handoff and reduces the overall handoff completion time.

1.5.2.3 Mobile Controlled Handoff (MCHO)

Mobile controlled handoff is a handoff scheme in which mobile node and base station both are responsible for RSS measurement, but handoff decision is taken by the mobile node. It gives full control to the mobile node to decide when and where to handoff.

1.6 Challenges in Seamless Mobility

In maintaining a wireless communication network to provide seamless mobility and QoS to the user, an improved handoff decision making scheme is required which can avoid the Ping-Pong effect, reduces the number of unnecessary handoffs without affecting handoff performance. Usually, many applications are used by the user or UGV, from surveillance to rescue operations and warehouse management. Each application has its own priority for the network parameters i.e., in surveillance video feedback is required which works best when bandwidth is high, and in warehouse management related task, RSSI is given more importance while rescue operations utilizes both video feedback and control traffic classes to achieve their objectives. To design a handoff management scheme in such cases, using only one traffic classes can affect the performance of the UGV. The handoff decision should be made which should include the working of multiple application requiring different priority of network parameter.

There is a trade-off between number of handoffs and handoff performance. By reducing the number of handoffs, UGV performance can be optimized, and power cost can be reduced but decreasing the number of handoffs through a certain limit increases the chances of no-handoff occurrence i.e., reducing the handoff performance.

Operating in the center of the converging of two access points (APs) leads to the continuous switching of networks i.e., continuous handoffs. This effect is called Ping-Pong effect. The effect can be reduced by using different handoff criteria for performing handoffs.

1.7 Research Contribution

The impact of proposed research covers many research areas related to handoff and mobility in wireless networks. Improving handoff decision making by:

- Utilizing multiple traffic classes and network parameters with respect to UGV functionalities.
- Priority assignment of network parameters according to each traffic class for parametric weight calculation.

- Incorporating multiple decision makers namely, network, user, and mobile terminal (i.e., UGV).
- Adopting proposed handoff criteria reduces the number of unnecessary handoffs using best and current performance values, and suitable threshold.
- Handoff analysis for number of handoffs and handoff response time using multiple threshold values.
- Avoiding Ping-Pong Effect

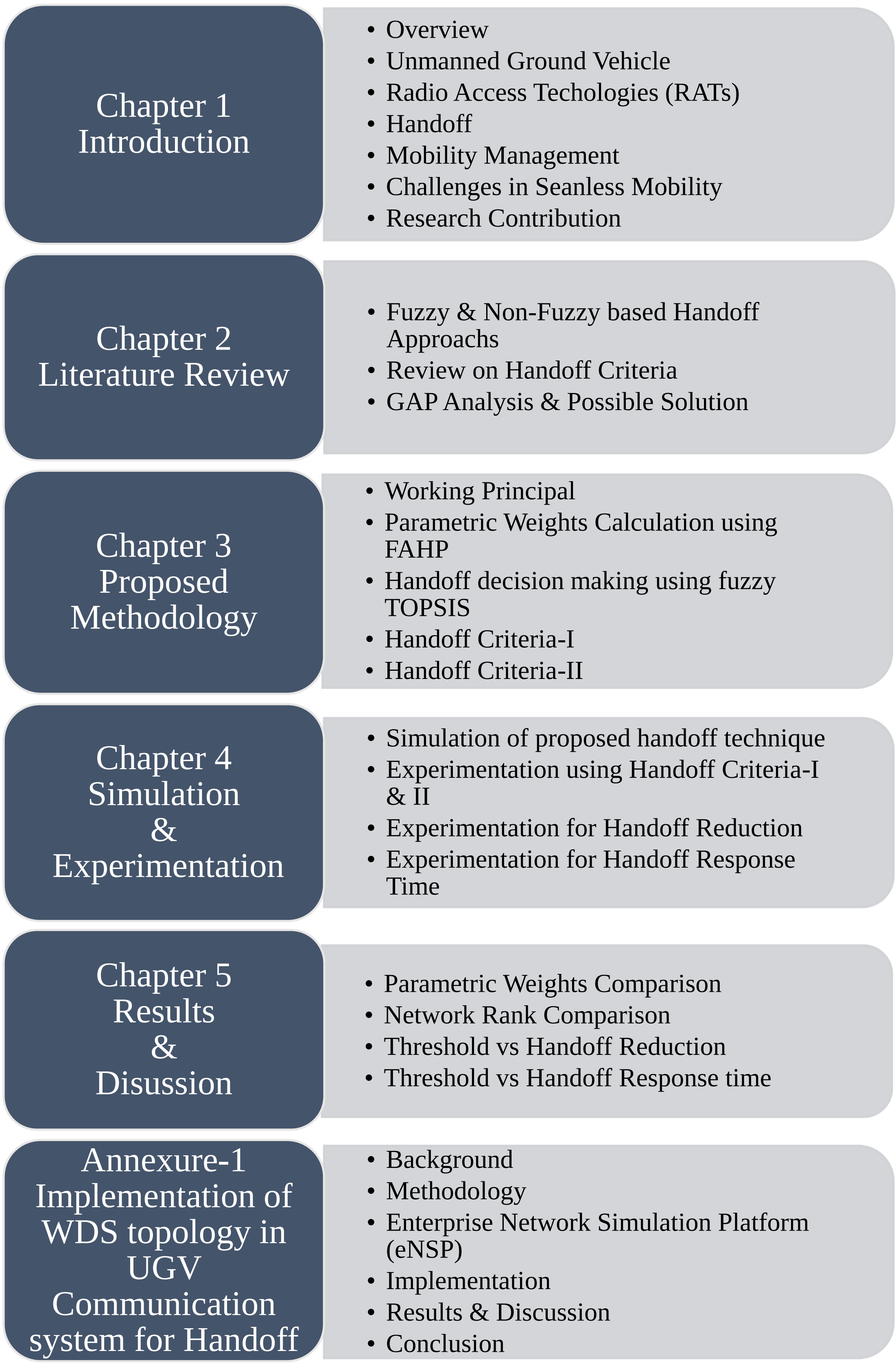

Figure 1.4 Flowchart of the Research

Chapter 2: Literature Review

In literature, handoff techniques have been proposed to obtain seamless mobility and improve handoff process in wireless networks. These techniques were based on fuzzy, non-fuzzy, MCDM, ANN and SDN algorithms. Each category has its own effects and has been improved over the years to optimize the handoff decision making for continuous connection while moving. This chapter explores the recent development in handoff decision making techniques in each category and identifies the research gap.

2.1 Fuzzy & Non-Fuzzy based Handoff Approach

The adoption of fuzzy based approach manages non-linguistic nature of network parameters and effectively aids in improving the handoff decision making and network selection procedure as compared to non- fuzzy based approach.

With non-fuzzy based approach gives more control over handoff criteria and is effective in pre-defined or specific application. Without defining fuzzy rule set, numerical methods are used for performance evaluation of available networks.

The recent improvements in fuzzy & non-fuzzy based techniques for handoff are discussed.

2.1.1 Fuzzy based-Handoff Decision System (Fuzzy-HDS)

A handoff decision making system is adopted for four network parameters i.e., Date rate, Packet loss, RSS, Security. The four network parameters are normalized using Fuzzy Normalization engine. In addition to above, four fuzzy engines are utilized in fuzzy based-handoff decision system (HDS). The NQ fuzzy engine takes normalized data rate and packet loss value to obtain quality value (Q_{value}). The RS engine uses normalized RSS and security to find RS value (R_{value}). The two output scores of each network are used by the decision system (DS) engine for evaluating the performance value [5]. The HDS algorithm uses pre-define maximum values of each network parameter for normalization. The output value of DS engine is used for handoff decision making.

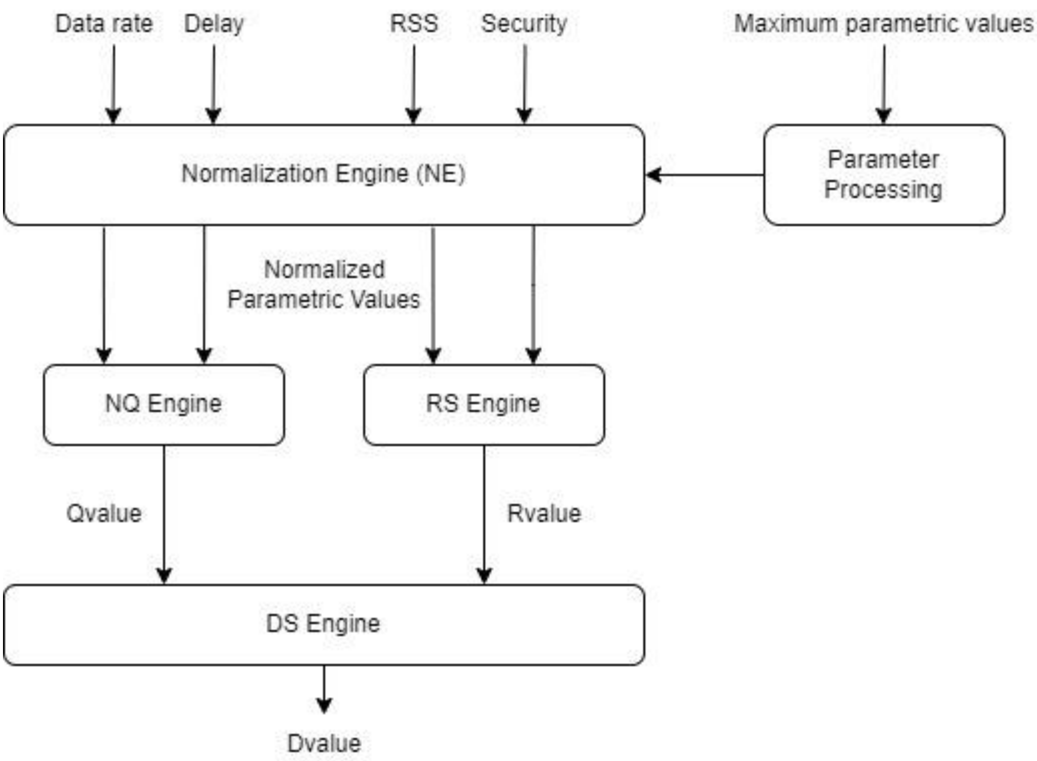

Figure 2.1 Flow Chart of HDS model

The fuzzy based HDS model is compared with selective additive weights (SAW), analytical hierarchal process (AHP) and other fuzzy techniques, which shows that the network selection of HDS is more efficient and is further enhanced by including parameter processing function to incorporate varying nature of maximum value of network parameter.

2.1.2 Fuzzy Utility Handoff Decision model

A fuzzy utility handoff algorithm with four membership functions, five network parameters and three traffic classes. The network parameter selected are RSS, delay, network load, SNR, and bandwidth. The traffic classes include voice, video, and data.

For selection of best available network, respective score, and weights of network parameters of each network are used. The fuzzy rules are formed using four membership functions i.e., yes (1), probably yes (0.7), probably no (0.3), and no (0.1). After defuzzification, if handoff score is greater than 0.6 then handoff is commenced [6]. The final performance value is evaluated using (1) as utility function.

$$U(x) = 1 - e^{-ax} \tag{2.1}$$

The results obtained using five network parameters and fuzzy utility function were compared to RSS based approach and shows considerable improvements with the increase in speed.

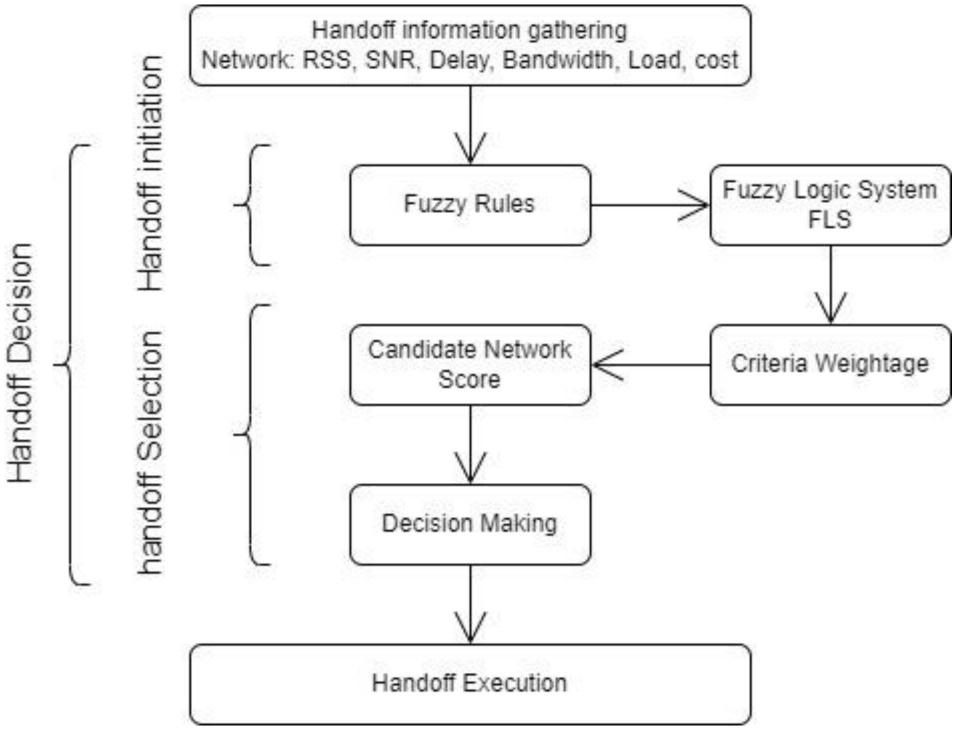

Figure 2.2 Flow Chart of Fuzzy utility handoff model

2.1.3 Fuzzy Logic with Grey prediction Handoff Algorithm

The fuzzy approach using five network parameters i.e., RSS, predictive RSS, load, delay, and power consumptions, utilized for multi-parametric handoff decision making. Predictive RSS is used to better understand the changing behavior of network. For this purpose, grey predictive technique is used to determine predictive RSS value. The parameters go through the process of fuzzification, fuzzy rules, inference and defuzzification.

Pre-defined weights are used with fuzzy logic membership functions to obtain performance value of each available network [7]. The highest performance value is selected to be the best available network. The results are compared with single parameter RSS based techniques and shows that it reduces the number of unnecessary handoffs and avoid ping-pong effect.

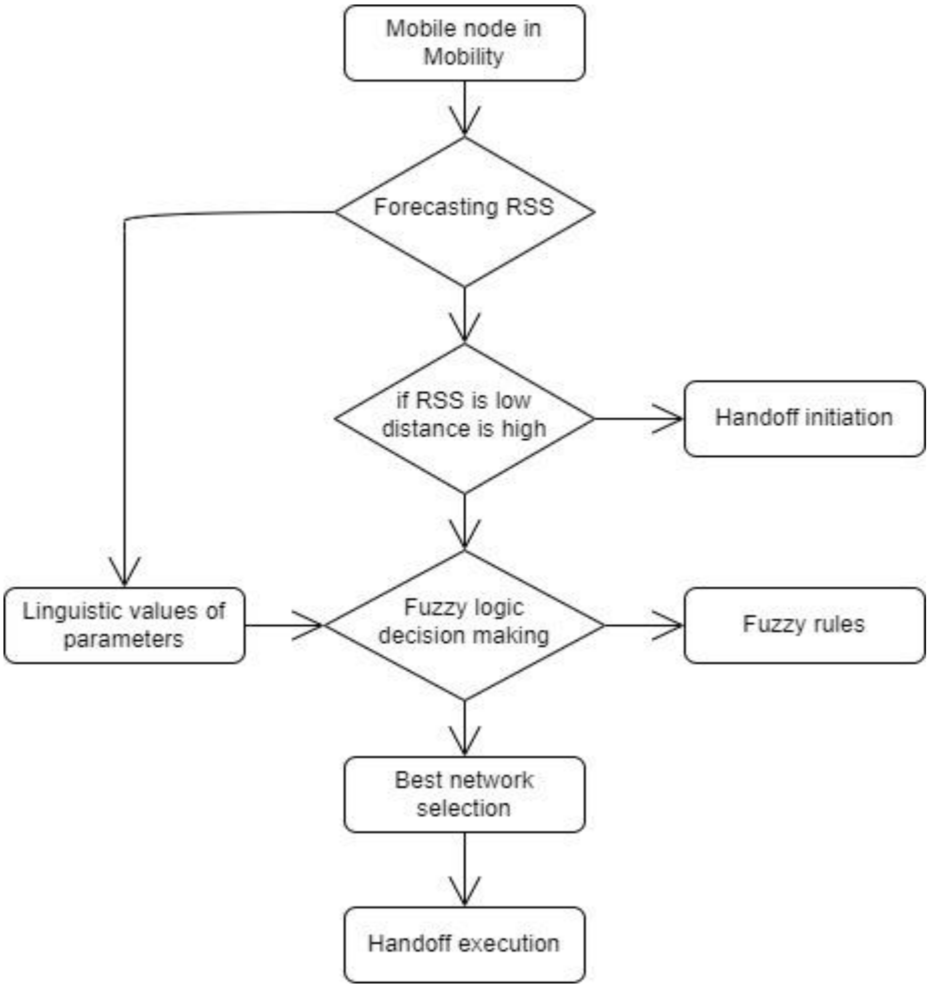

Figure 2.3 Flow Chart of Fuzzy based Grey Predictive scheme

2.1.4 Adaptive Fuzzy Handoff Algorithm

Mobile users in any wireless networks requires advance handoff decision making algorithms for better mobility and QoS. Fuzzy approach combined with intelligent handoff decision system (HDS) uses pre-defined fuzzy rule set and membership functions which leads to increased handoff time. The research in [8] proposed an improved fuzzy handoff decision system i.e., fuzzy based adaptive modular-handoff decision system design II (AMHDS-II). The adaptive technique utilizes six network parameters, three for QoS parameter i.e., jitter, latency, packet loss and throughput, power consumption, cost for efficiency and network QoS fuzzy engines. The quality and efficiency value obtained from these engines are used for determining degree of satisfaction in DS fuzzy engine and network ranks are defined using satisfactory value.

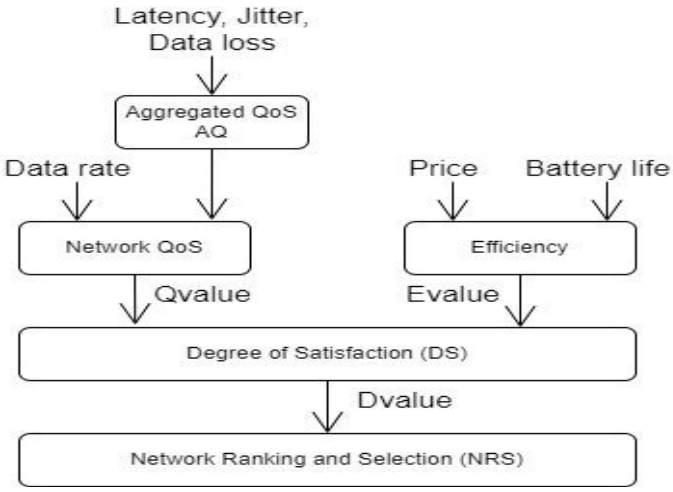

Figure 2.4 Flow Chart of AMHDS Design II

The network selection results of AMHDS II shows that it is better than existing HDS to some extent while considerable improvements were shown in comparison to non-fuzzy techniques i.e., SAW, AHP etc. The technique is shown to be effective for two traffic classes i.e., voice and video streaming. Necessary improvements are needed to improve the algorithm for mobility services by incorporating network parameters related to mobile services i.e., velocity, path-selection, handoff reduction.

2.1.5 Fuzzy based Network Controlled Handoff (NCHO)

To provide seamless mobility and QoS to user, a fuzzy based network-controlled handoff scheme was presented in [9]. Using three network parameters i.e., velocity, network load, and bandwidth, for generating performance value of each network involving different RATs i.e., heterogeneous wireless networks.

The fuzzy rule base inference system was used to make handoff initiation criteria. The decision value generated using fuzzy was utilized by handoff criteria shown in fig.

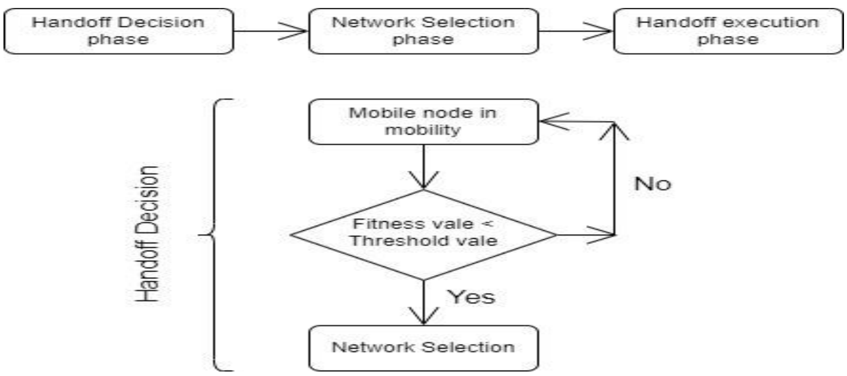

Figure 2.5 Flow Chart of fuzzy based handoff criteria

Although it provides QoS and better mobility for mobile node but there is need of handoff reduction criteria and process to cater ping-pong effect which can affect the performance of mobile node in a network.

2.1.6 Simple Additive Weighting with AHP for vertical handoff

Multi-attribute handoff decision technique was proposed using simple additive weighting for performance evaluation of available networks and using AHP for weights calculation of SINR, required bandwidth, cost, and available bandwidth [10]. The algorithm is proposed to be effective for traffic and user. The algorithm needs considerable improvements in network selection and handoff decision making.

2.1.7 Fuzzy interference and AHP for heterogeneous networks

To improve the network selection, reduce unnecessary handoffs, and avoid ping-pong effect, fuzzy interference was adopted in [11]. AHP and FAHP were utilized for parameter selection and weights calculation. The Fuzzy rules are used along with weights obtained from FAHP for evaluating performance value of each network.

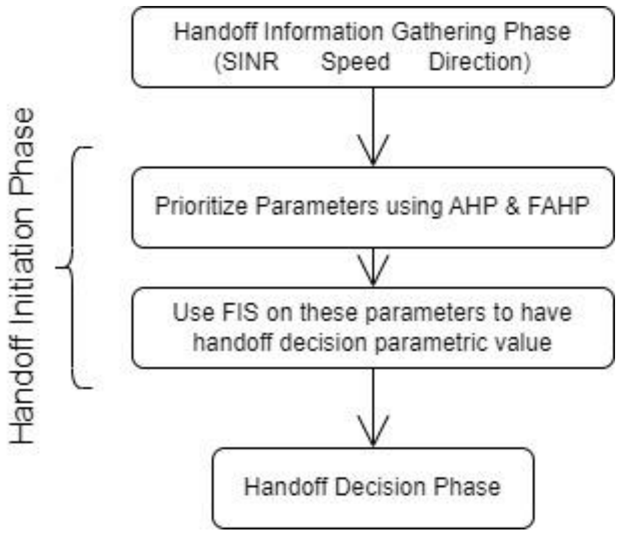

Figure 2.6 Flow Chart of FAHP & Fuzzy interference model

Using three inputs or network parameters and three membership functions, twenty-seven fuzzy rules were defined for handoff decision value. The final value was de-fuzzified for making handoff decision. The threshold value is set to 0.5. The results show improvements in QoS and reduction of unnecessary handoffs. Taking handoff value directly for comparison to threshold increases the chances of ping-pong effect.

2.1.8 Artificial Neural Networks based on Fuzzy Logic for Handoff

Artificial neural networks (ANN) based on fuzzy logic for vertical handoff scheme utilized for the selection of best available network uses three network parameters i.e., RSS, cost, throughput. Fuzzy logic was adopted for incorporating its human expert reasoning feature [12]. The combination of ANN and fuzzy logic produces handoff time limiting technique with the benefits of handoff reduction. The results are compared with existing SAW method and MCDM techniques which shows that ANN was more suitable in terms of reduction of handoff process time.

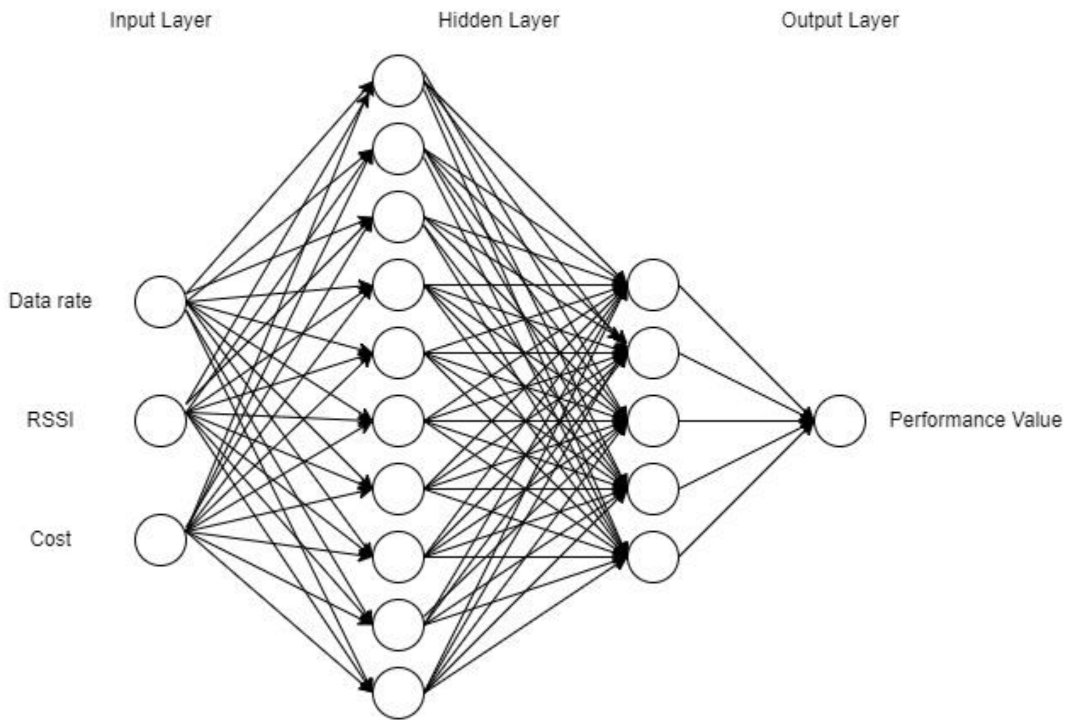

Figure 2.7 Flow Chart of ANN based Fuzzy Logic

The handoff initiation criteria can be improved by not using performance value of best network directly. By doing so, ping-pong effect can be avoided, and unnecessary handoffs can be reduced.

2.1.9 Handoff Management using Neighbor Tables

Handoff management techniques focused on reducing handoff delay and processing time while maintaining quality of connection (QoC) with best available network utilize neighbor tables. As the name suggest, the table contains the information related to each accessible access points (AP) to the mobile node at that moment. The network-controlled handoff is adopted using distance-based approach between mobile node and access points [13]. The availability of network decides the next suitable network from top to bottom in neighbor table.

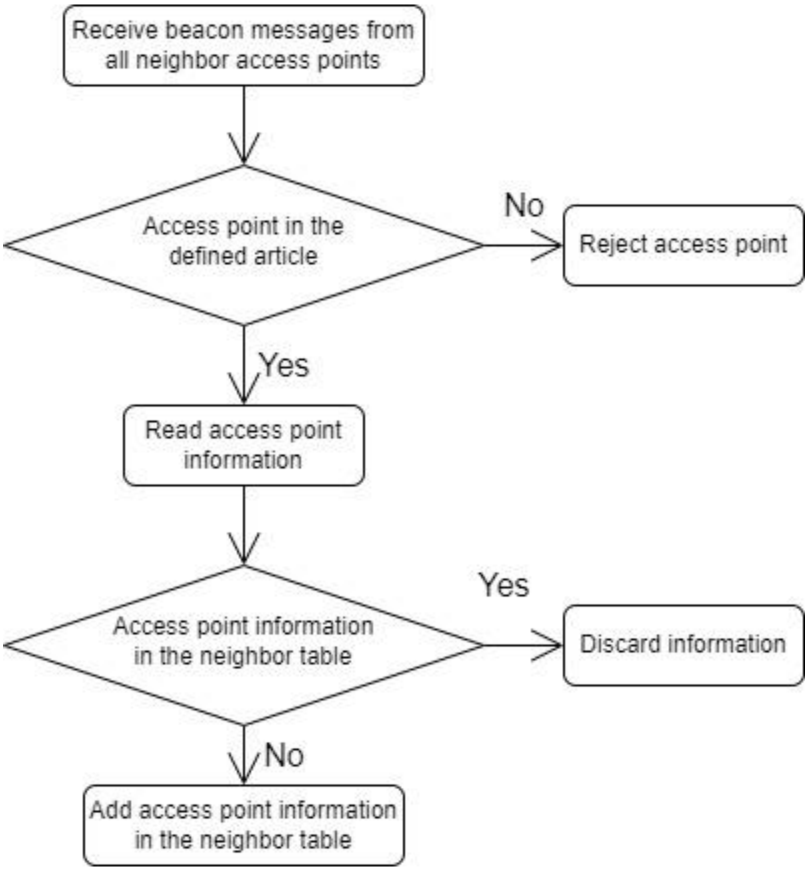

Figure 2.8 Flow Chart of neighbor table algorithm

The current access point is utilized in maintaining its communication with neighbor access points through beacon messages. The number of clients and handoff delay increases with the increase of number of access points. Without handoff initiation criteria handoff can occur multiple times due to environmental interference and ping-pong effect which can reduce the handoff performance and increase power consumption.

2.1.10 Modified optimization of Vertical Handoff in Heterogeneous networks (M-OPTG)

The research in [14] provides an optimization technique for vertical handoffs between wireless and cellular networks i.e., 3G and WLAN, based on network load balancing and power consumption. The algorithm aims to achieve a heterogeneous network with load minimization and less power consumption. The optimization parameters are load distribution, remaining battery life, number of nodes, velocity, and call drop-rate.

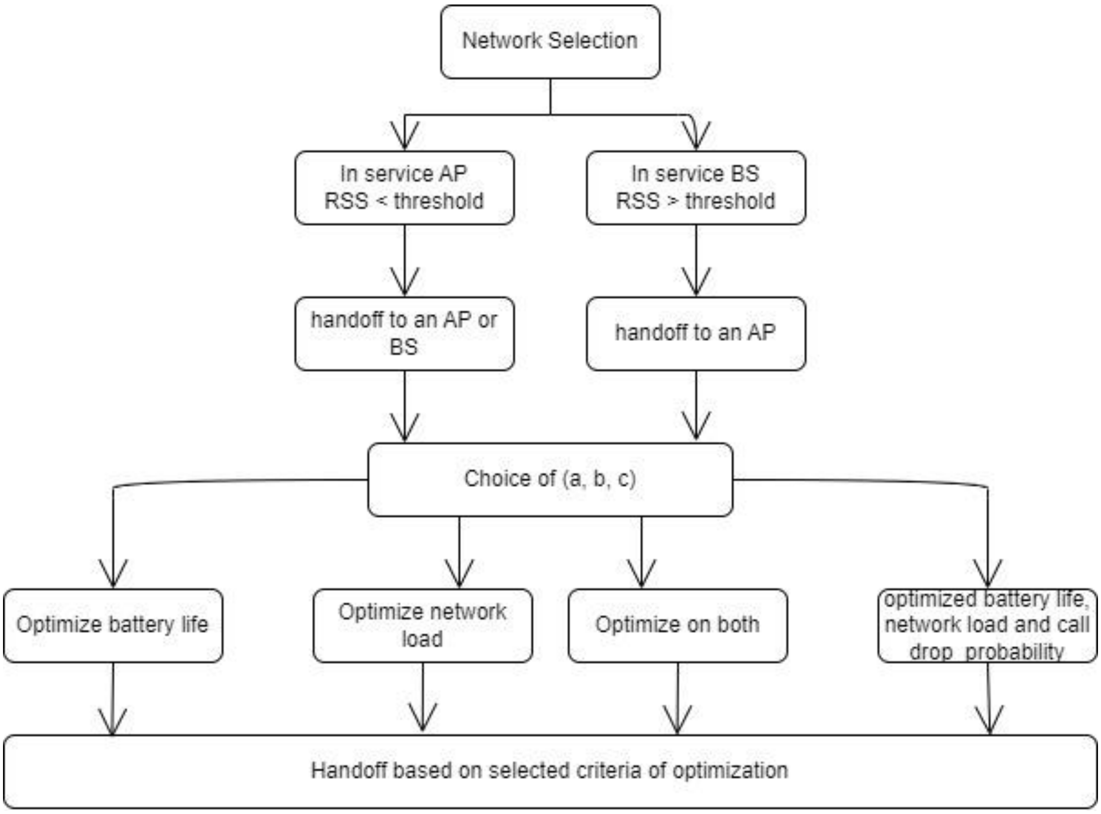

Figure 2.9 Flow Chart of M-OPTG based VHO

The results are compared with strongest signal first (SSF) and existing OPTG techniques, which shows that M-OPTG increases battery life performance, decreases call dropping rates and provide better load balancing than SSF and existing OPTG. The RSS based handoff initiation criteria was used which can increase the chances of unnecessary handoffs and system can be affected by ping-pong effect. Including priority weights can increase the performance of handoff.

2.1.11 Chi-Square distance based Vertical Handoff Algorithm

An improved distance based vertical handoff algorithm modified for finding best available network based on the distance of each available network with ideal scenario. The algorithm is assessed for six network parameters with weights calculation using AHP and different traffic classes. The Chi-square distance evaluated in [15], uses difference of network parameters value of available and ideal network.

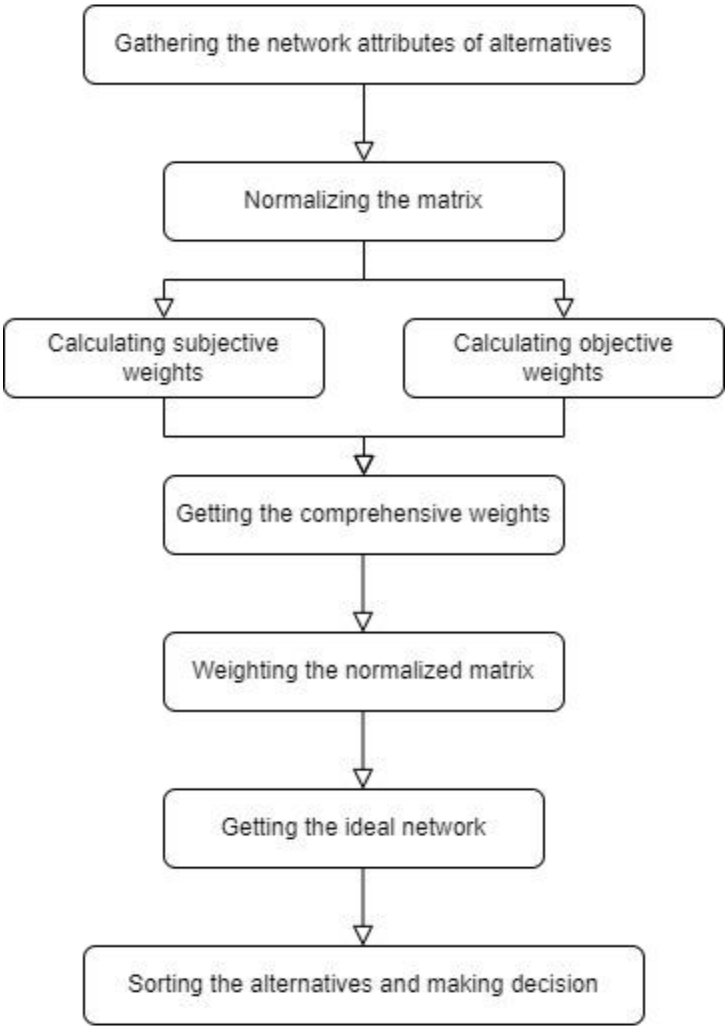

Figure 2.10 Flow Chart of Chi-Square distance based VHO

The Chi-square based approach was proposed to be effective in handoff execution. Its comparison was done with SAW, and other MCDM techniques which provide evidence that chi-square approach avoids local maxima and find best available network. The technique requires a handoff initiation criterion which decreases the chances of ping-pong effect and reduces number of unnecessary handoffs. The parameter should be selected depending on the require traffic classes with priority levels to increase overall performance of best network selection process.

2.1.12 Media independent Handoff function (MIHF) with Network Simulator 2

A multi-layered handoff technique was proposed in [16] based on IEEE 802.21 specifications using media independent handoff function defined in network simulation-2 (NS-2) software. The network is composed of universal mobile telecommunication service (UMTS) and wireless local area network (WLAN) overlapping cells.

The network parameters selected for handoff decision making was velocity of mobile node and coverage area of available networks. The handoff decision was made in accordance with mobility required and range of connection. No criteria for reducing unnecessary handoffs and ping-pong avoidance were proposed which affects the implementation of such techniques in handoff decision making.

2.1.13 Optimized Handoff decision making with SINR based Initiation criteria

To obtain QoS for different network applications, handoff management techniques with optimization strategy based on beneficial and non-beneficial parameters were studied [17]. Power consumption, remaining capacity of network, SINR, and handoff cost were taken as network parameters for available networks. Parametric weights and multiple traffic classes i.e., voice and data, were included in the study of handoff decision making to make it applicable for more than one application. The performance values of each available networks were not combined to obtain final decision which makes it suitable for one application at a time.

The handoff initiation criteria based on current and require SINR value was adopted. The difference of current and required SINR value is monitored over time to decide the initiation of handoff. The simulation results represent the avoidance of ping-pong effect and selection of best available network.

2.1.14 Weighted Rating of Multiple Attributes and TOPSIS for Seamless Mobility

Evaluation of parametric weights and selection of best available network are key steps in handoff management. Weighted rating multiple attributes (WRMA) technique was adopted for parametric ranking which is simpler and more effective than SAW and traditional techniques [18]. Addition of TOPSIS for network selection and handoff decision making, based on rankings obtained from WRMA, improve the overall handoff performance. Delay, jitter, bandwidth, error, and cost were chosen as network parameters.

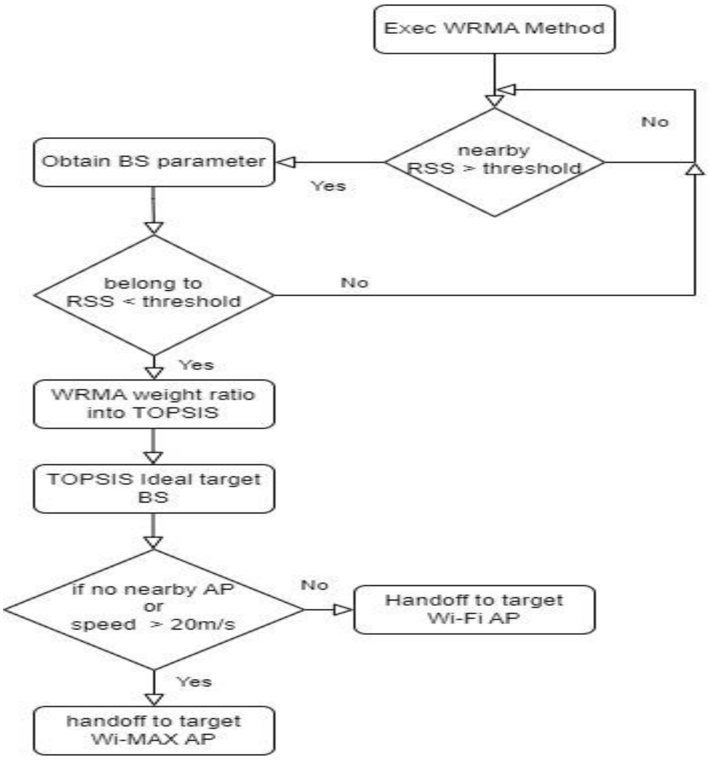

Figure 2.11 Flow Chart of WRMA & TOPSIS based Handoff

The handoff algorithm is compared with AHP and SAW based networks and results proved to be in favor of TOPSIS i.e., TOPSIS came out to be more effective and precise in network selection for handoff. The algorithm needs improvements in handoff initiation criteria to include features of unnecessary handoff reduction and avoidance of ping-pong effect.

2.1.15 Handoff between Wireless long-term evolution (LTE) networks and Cellular networks

The handoff management in heterogeneous wireless networks had remain a problem for LTE and Cellular networks. A survey was done to discuss handoff techniques to better understand the concept of handoff decision making involving LTE and cellular networks [19]. The advantages and disadvantages of adopting handoff techniques while presenting fundamental problem faced for seamless mobility and QoS in heterogeneous wireless networks.

The survey describes the major problems faced in LTE networks with high-speed mobility. Involving mobile users with high speed, packet loss, cell estimation, signal interference, and increased number of handoffs are major concerns which increases the power consumption and affect the performance of required application. Four major domains regarding challenges in LTE and cellular networks are:

1. Network selection
2. Signal processing
3. Optimized placement of base stations
4. Mobility management

To improve selection of network in high-speed mobile devices, dual-hop network based on RSS mobility management technique was adopted which proved to be effective in mobility management by reducing number of handoffs and power consumptions.

The handoff management is also utilized in internet of vehicles (IoV). The handoff between LTE and mm Wave 5G networks were studied in [20]. Q-learning based handoff initiation criteria was adopted to estimate the threshold for the given environmental conditions. To achieve this, two network parameters i.e., RSS and speed are used. The network selection and handoff decision were taken using quick convolution based fuzzy neural network algorithm utilizing five network parameters and thirty-two fuzzy rule sets.

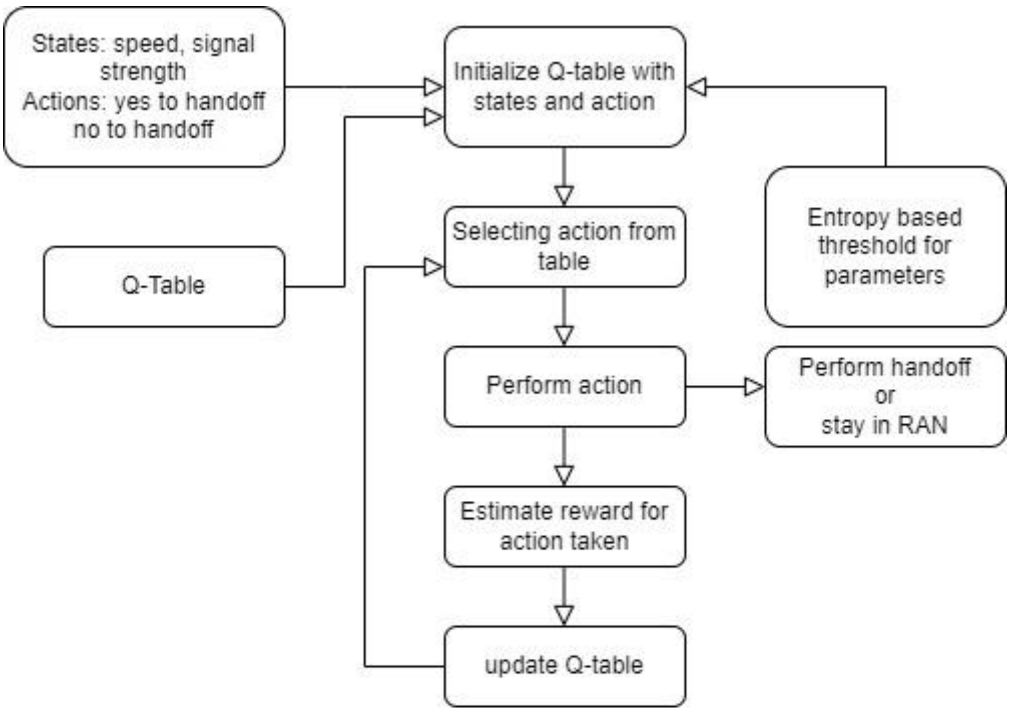

Figure 2.12 Flow Chart of Q-learning based Fuzzy CNN

The vehicle to vehicle (V2V) communication and path selection was under the control of jellyfish algorithm with three metrices i.e., vehicle, channel, and vehicle performance metrices. The performance analysis of handoff was done by monitoring number of unnecessary handoffs, handoff failure, throughput, delay and packet loss.

2.1.16 SDN based approach in wireless networks for Handoff

Software defined networks (SDN) coupled with fuzzy logic were used to increase the QoS and reduction of unnecessary handoffs [21]. Multiple parameters which include RSS, predicting RSS, and bandwidth were selected for decision making process using fuzzy logic. The inclusion of layered processing improves the algorithm for handoff reduction and network load balancing thus improving the network QoS.

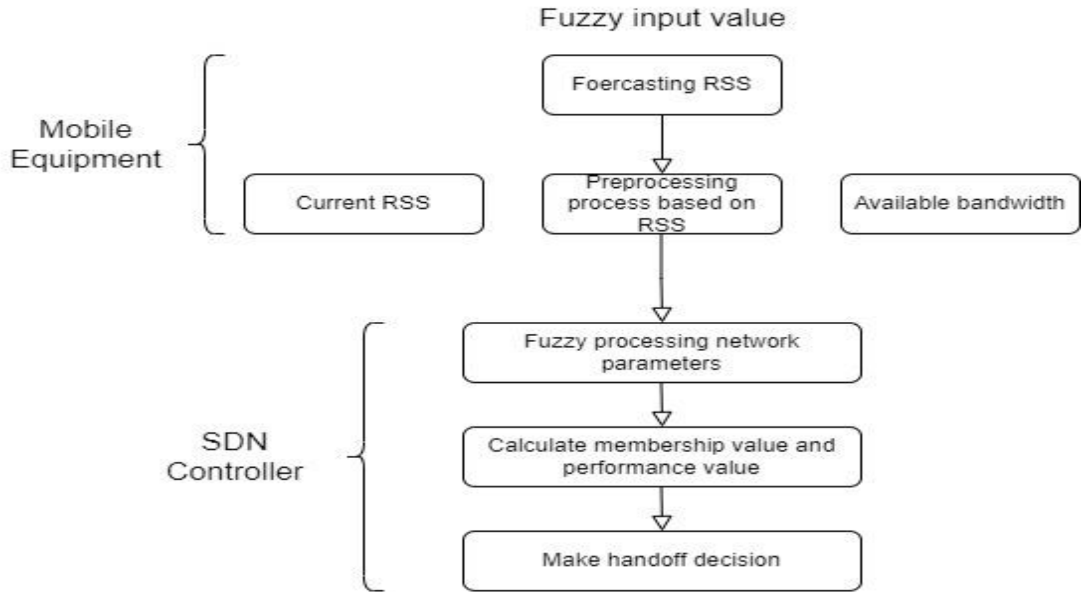

Figure 2.13 Flow Chart of SDN based handoff

The fuzzy membership function and performance value of each available network were calculated by SDN using parametric value from fuzzy inference engine. The adoption of fuzzy based approach improves the precision of network selection process in homogenous wireless networks. Necessary enhancements are needed to improve the algorithm for smooth and seamless mobility in heterogeneous wireless networks by increasing the number of parameters and incorporating priority-based traffic classes.

2.1.17 Handoff in LTE Femto-cells networks

Femtocells having small range and power conduction compels to increase the number of femtocells as studied in [22]. The increasing number of femto-cells increased the number of handoffs. Due to which power regulation may not be stable for some cases as well as network load.

To maintain power consumption and network load in LTE femto-cell networks, network load is shared with neighboring APs and new users were welcomed in the targeted femto-cell. The adoption of this technique improved the time delay between handoff while increasing the data rate at the cost of increasing number of handoffs. Handoff initiation criteria is needed to improve the avoidance of ping-pong effect.

The solution to increase in number of handoffs and inclusion of handoff criteria was provided by enhanced handoff algorithm in femto-cells. RSS bases handoff initiation criteria is utilized while monitoring speed of the mobile terminal with targeted femto-cell [23]. The handoff was initiated when RSS drops below a certain level and RSS value of target femto-cell was also monitored to check its network capacity and QoS for the mobile terminal. Multi-layered networking architecture of macro-cells and femto-cells were utilized for network load management and smooth handoff process.

In [24], group handoff scheme in LTE-A networks were studied and improved handoff algorithm was developed. Two types of base stations i.e., target node (T-DeNB) and station node (S-DeNB), were utilized in handoff process. Decrease in RSS value of S-DeNB initiates handoff and RSS value of T-DeNB was measured to execute handoff for mobile relay. The embedded system utilized aided in the handoff process for each user in mobile relays.

The results are compared with existing handoff algorithm for LTE-A networks for number of handoffs and call dropping rates. The adopted handoff scheme used grouped based technique to decrease the number of unnecessary handoffs and handoff processing time.

2.2 Review on Handoff Criteria

Handoff criteria is utilized in mobility management techniques to reduce the handoff frequency, by doing so power consumption is also reduced. The addition of handoff criteria in handoff decision making algorithm serves as a gateway for handoff initiation and is mostly adopted to define:

1. When should a handoff occur
2. Where should the mobile node switch to

In some cases, prediction-based handoff criteria were used to predict the behavior of network parameter for decision making. Hence handoff criteria are important factor in optimized handoff decision making. The survey conducted in [25], four group types were categorized depending on the nature of network parameter i.e., RSS based, bandwidth based, cost-function based and combination algorithm-based handoff criteria. According to the findings of the survey, utilizing RSS based handoff criteria reduces the number of unnecessary handoffs effectively but cannot effectively maintain the throughput with higher speeds, bandwidth-based criteria give greater throughput and better handoff delay but needs improvement in handoff reduction scheme, cost-based criteria give less delay and handoff failure probability while combination algorithms take longer handoff delay time for training of data and reduce unnecessary handoffs by avoiding ping-pong effect.

Some of the recent studies regarding the above discussion are as follows:

2.2.1 RSS based Handoff Criteria

In traditional RSS based handoff criteria, handoff was initiated when RSS value goes down a certain threshold. Using only RSS value for handoff initiation was creating problems related to number of handoffs and power cost. The criteria improved in [26], included multiple network parameters in addition to RSS for handoff initiation. The overall procedure involved monitoring of RSS value as first step while the cumulative cost of other network parameters i.e., Delay throughput and handoff cost, was used to determine the necessity of handoff. The flowchart of mentioned algorithm is shown in Fig. 2.14.

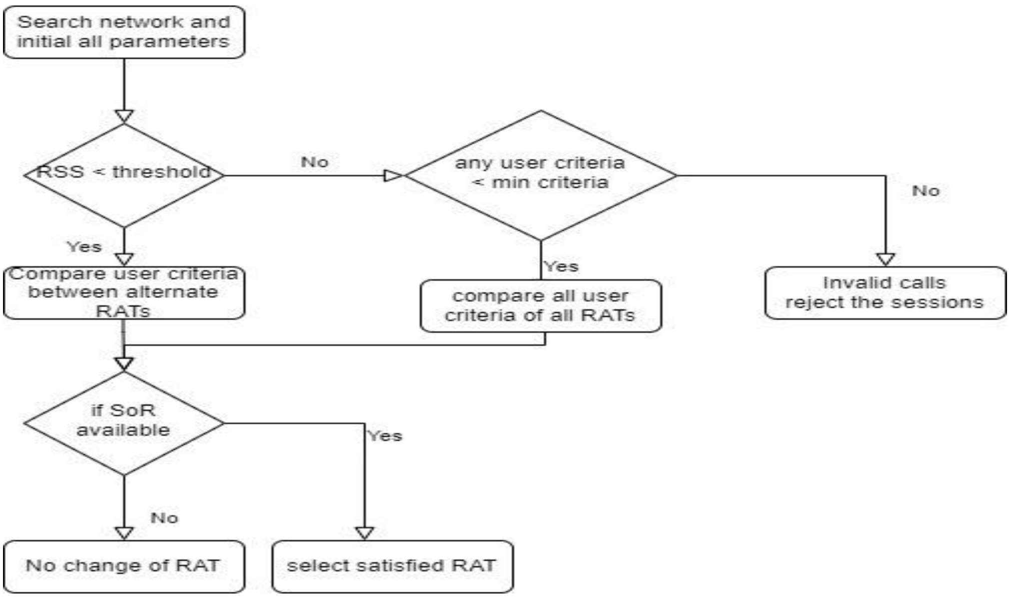

Figure 2.14 Flow Chart of improved RSS based handoff

2.2.2 QoS based Handoff Criteria

The quality of the network is defined by the predictability of varying network parameters, hysteresis, and defined threshold for handoff. The quality-based handoff scheme described in [27] utilized these QoS parameters for handoff initiation along with RSS. The predictive RSS, hysteresis and threshold value are constantly monitored and whenever any one of the parameters decreases from the defined level, system was tested for handoff. The flow chart of QoS based handoff technique is shown in Fig. 2.15.

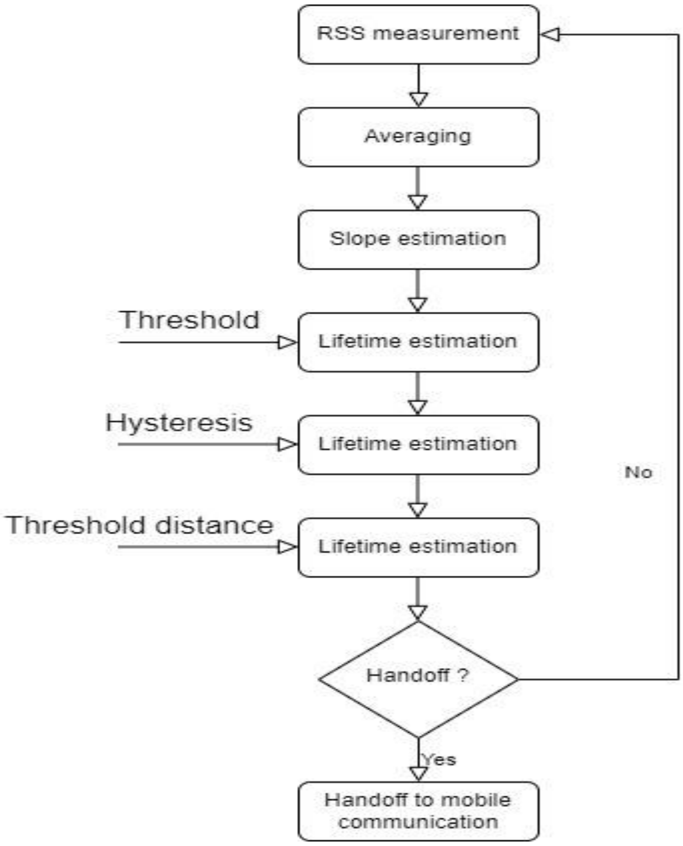

Figure 2.15 Flow Chart of QoS based handoff

2.2.3 Decision Function based Handoff Criteria

Decision function-based handoff initiation criteria used multiple parameters in evaluating the cost or ranks of each available network [28]. The decision was taken on those values based on comparison between current and best networks as in Fig. 2.17. MCDM, utility function, cost analysis and network score evaluation were some of the handoff decision-making algorithms which utilized the concept of decision function for their handoff criteria.

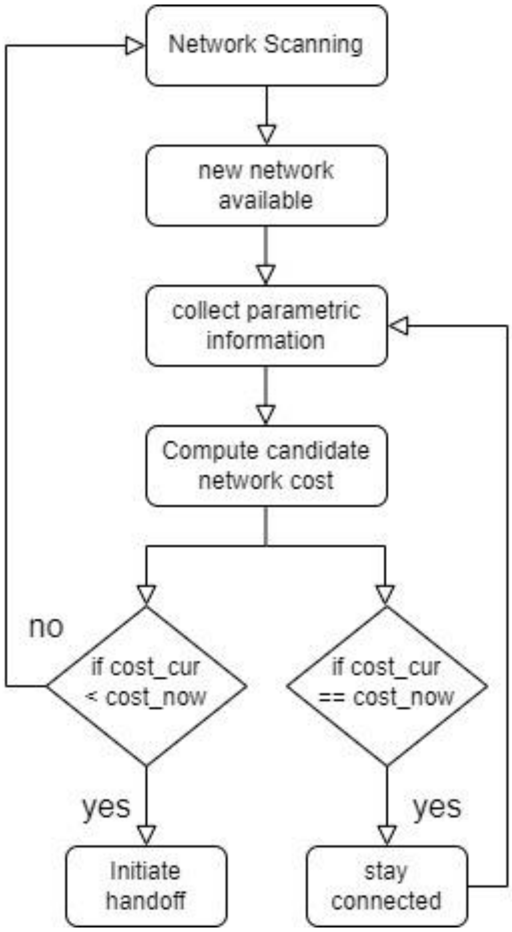

Figure 2.16 Flow Chart of Decision function-based Handoff Criteria

2.2.4 Moving Slope Average based Handoff Criteria

Handoff algorithm using moving slope average of network parameter was taken as deciding factor for handoff initiation [29]. The RSS and SNR based approaches were discussed. Based on the referred article, deploying RSS moving slope average and its comparison with the set threshold, reduces the number of handoffs. The negative slope value represents decrease in RSS value and positive slope value means increase in RSS value. Handoff was initiated whenever the difference increases the set threshold. But the point to concern is that the more-negative or more-positive value of RSS will initiate handoff more quickly and lower values of RSS can also mean that RSS value of current network was stable and do not need to switch.

In some cases when the value of moving slope of RSS remained low for a certain amount of time but difference was greater than threshold, so no handoff occurred. Although the current RSS value of the network was very low. The problem was solved by using another parameter i.e., signal to noise ratio (SNR) in handoff initiation criteria. Second condition now becomes that handoff should initiate whenever SNR value drops from a set threshold. The network that satisfies both conditions was selected and even if one of the conditions fails then handoff will be initiated.

2.3 GAP Analysis and Possible solution

The study done in above sections describes the two important aspects of handoff decision making which are handoff decision making algorithm based on the information related to the network parameters and handoff initiation criteria for reduction of unnecessary handoffs, power optimization, and avoiding ping-pong effect.

The recent studies of vertical handoff in heterogeneous wireless networks provide the detailed solutions to the problem at hand and utilized different handoff criteria to optimize the handoff process but the need of better handoff decision making, and handoff initiation criteria is also prominent.

To increase the effectiveness of the handoff process and improve QoS for the user desired specific applications, network parameters having high priority for the desired applications should be selected. Each traffic classes should be defined based on the required functionalities of the mobile node. The handoff decision making algorithm can be further improved by deploying parametric weights under each traffic classes, which can later be used in network selection. To utilize the parametric weights for evaluating performance value of available networks, different MCDM or algorithms involving multiple parameters can be used. In [30], different fuzzy based MCDM techniques were studied to solve the house selection problem. The article discussed multiple parameters involved in decision making for house selection. Fuzzy based approach was used to incorporate non-linguistic parameters and impersonate human like thinking.

Rankings obtained from those fuzzy based MCDM techniques were compared for ranking similarity coefficient. Most of the results coincides with each other which prove that selection process works well. Fuzzy based technique for order preference by similarity to ideal solution (TOPSIS) and fuzzy based weighted aggregated sum product assessment (WASPAS) were proved to be most effective in decision making as per the similarity index while fuzzy based VlseKriterijumska Optimizacija I

Kompromisno Resenje (VIKOR) showed most variation in similarity index when compared to other techniques.

The handoff initiation criteria should not be limited to one or two parameters otherwise it can result in increasing the chances of unnecessary handoffs and false handoffs requests. The chances of ping-pong effect also hinder the performance of handoff process.

Chapter 3: Proposed Methodologies

3.1 Working Principle

The proposed handoff method utilizes the network parameter selection based on their ranks for three decision makers i.e., network, UGV, and user-preference, given in [31]. Priority levels of each network parameter in each traffic class i.e., video, control, and background, are assigned based on their ranks. The priority levels are used to obtain pair-wise comparison matrix for each traffic class. The process involves five importance levels with four intermediate and inverse comparison values each. The importance criterion is used to compare importance of network parameter with each other to form pair-wise comparison matrix.

Fuzzy Analytical hierarchal process (FAHP) uses the pair-wise comparison matrix for obtaining fuzzy weights. Pair-wise comparison matrix goes through the process of fuzzification, and geometric mean of each network parameter is calculated. Fuzzy weights of each network parameter are calculated by normalization of fuzzy geometric mean. Each fuzzy weight contains three values i.e., one value for each membership function. Parametric weights of the three traffic classes are calculated by repeating the same steps.

For making a handoff decision, available networks are ranked based on their performance values using fuzzy technique for order preference by similarity to ideal solution (Fuzzy TOPSIS). The performance value of each available network depends on their parametric values. The information related to network parameters of different network parameters are converted into fuzzified decision metrices. The fuzzy weights and decision metrices are combined to obtain single fuzzy weights and decision matrix. The product of parametric weights and decision matrix is taken after normalizing the combined decision matrix. Fuzzy TOPSIS uses ideal and worst solutions based on the weighted combined decision matrix. The closure coefficient (CC) value of each network is calculated by their comparison from these solutions. The CC values determine the rank of available networks by giving high ranking to networks with high values of CC.

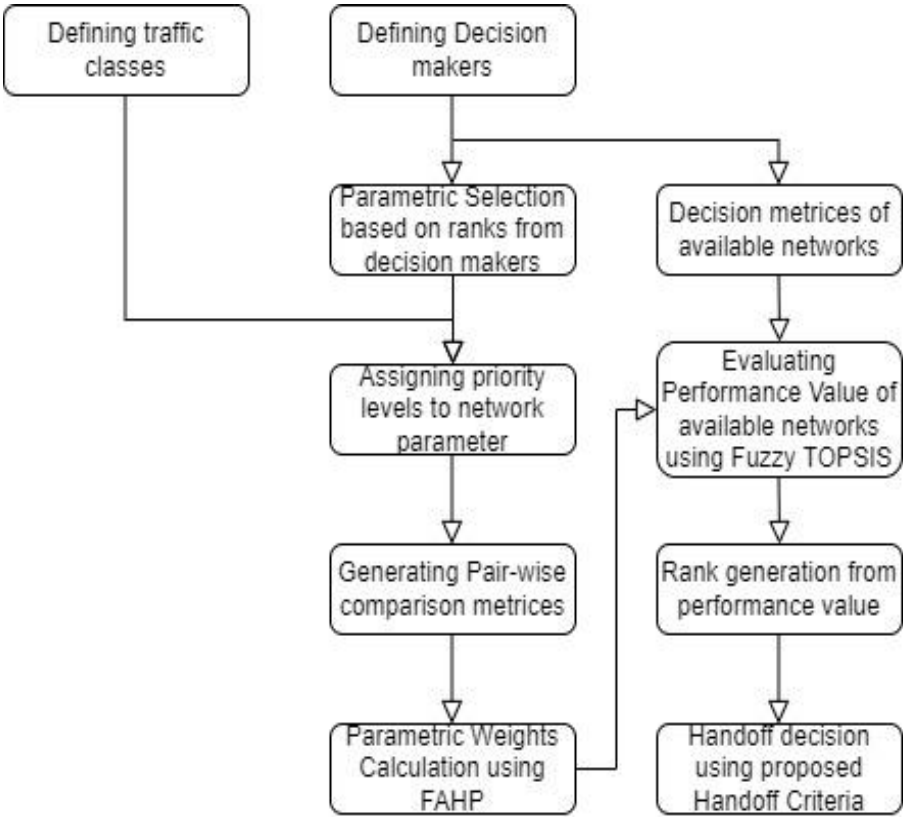

Figure 3.1 Flow Chart of working principle of proposed technique

Along with handoff decision making technique, handoff criterion is also proposed to ensure the preservation QoS and avoid performance degradation phenomenon i.e., Ping-Pong effect etc.

3.2 Handoff Management Methodology

The proposed handoff decision making technique for mobility in wireless networks uses networks parameter selection process based on their ranks in three decision makers i.e., network, mobile node, and user. The traffic classes used are based on the functionalities of UGV and network requirement which are mentioned below:

1. Video
2. Control
3. Background

The video and control traffic classes are used to define the video feedback and control signal part of UGV communication network in handoff decision making. The background class is used for including other applications running in UGV. The three traffic classes are different and have different preferability for each network parameter.

Following are the main steps involved in proposed handoff management technique which are further discussed in detail.

- Parameter Pair-Wise Comparison matrix
- Parametric Weights Calculation using FAHP
- Handoff Decision making using Fuzzy TOPSIS

3.2.1 Parameter Pair-Wise Comparison matrix

Network parameter selection process uses the ranks of network parameters for three decision makers i.e., network, mobile node, and user-preference. To obtain ranks of multiple network parameters article [31] is used in which network parameters are ranked from 1 to 10 by conducting a survey on individuals related to the field. The parameters having high rank are:

1. Received signal strength indicator (RSSI)
2. Bandwidth (BW)
3. Signal to interference & noise ratio (SINR)
4. Network delay (ND)
5. Data Loss (DL)
6. Bit error-rate (BER)

The selected network parameters are assigned to their priority level for each traffic class. Each traffic class has its own priority order for network parameter which is defined in the Table 3.1 The RSSI and BER are given high rank in control class as compared to other traffic classes while BW and ND are given more importance than other network parameters because in video feedback high bandwidth and low network delay are preferred.

Table 3.1: Priority Order under each Traffic Class

Rank	Video	Control	Background
1	BW	RSSI	RSSI
2	ND	BER	BW
3	BER	DL	SINR
4	DL	ND	ND
5	RSSI	SINR	DL
6	SINR	BW	BER

The Table 3.1 is utilized to form the pair-wise comparison matrix for each traffic class. The network parameters are compared with each other to obtain their importance level. The importance level is categorized into five stages i.e., equally, moderately etc. The Table 3.2 shows the categorization of importance level and their numeric representation in simple and fuzzy values.

Table 3.2: Categorization of Importance Level

Numeric Value	Importance Level	Inverse Numeric Values
1	Equally	1
3	Moderately	1/3
5	Strongly	1/5
7	Very Strongly	1/7
9	Extremely	1/9
2,4,6,8	Intermediate Values	

The obtained value of importance level forms the pair-wise comparison matrix which is a square matrix of the order n x n, where n is the number of network parameters.

3.2.2 Parametric Weights Calculation using FAHP

The parametric weights are calculated using FAHP – geometric mean method. The comparison matrix obtained goes through three step process to achieve final fuzzy weights. These steps are:

1. Fuzzification
2. Geometric Mean calculation
3. Fuzzy Weights calculation

3.2.2.1 Fuzzification

The process of fuzzification involves calculation of three membership values for each entry in comparison matrix. The simple and inverse numeric values of importance level are converted into fuzzy values using the Table 3.3.

Table 3.3: Fuzzification Criteria

Numeric Value	Fuzzy Value	Inverse Numeric Values	Inverse Fuzzy Value
1	1,1,1	1	1,1,1
3	2,3,4	1/3	1/4, 1/3, 1/2
5	4,5,6	1/5	1/6, 1/5, 1/4
7	6,7,8	1/7	1/8, 1/7, 1/6
9	9,9,9	1/9	1/9,1/9,1/9

The inverse of the fuzzy value is generated using (3.1).

$$(\alpha,\beta,\gamma) = (\frac{1}{\gamma},\frac{1}{\beta},\frac{1}{\alpha}) \tag{3.1}$$

3.2.2.2 Fuzzy Geometric Mean Calculation

The fuzzy geometric mean (GM_f) for each row in fuzzified pair-wise comparison matrix is evaluated. The task is done by using (3.2)

$$GM_f = \sqrt[n]{\prod val_j} \tag{3.2}$$

Where val_j is the fuzzy values for jth column of fuzzified comparison matrix and n is the number of network parameters used.

3.2.2.3 Fuzzy Weights Calculation

To calculate fuzzy weights of each network parameter, the fuzzy geometric mean of each network parameter is normalized by the summation of fuzzy geometric mean of all network parameters. The normalization process maps the fuzzy weights from 0 to 1 using (3.3).

$$fuzz\_weight_i = FGM_i \times (\sum_1^n FGM_k)^{-1} \tag{3.3}$$

where $fuzz\_weight_i$ represents fuzzy weights for i_th network parameter, FGM is fuzzy geometric mean, i = 1,2,3, …, n, and n is the number of network parameters.

The step can also be performed by replacing the FGM_i with the column matrix of fuzzy geometric mean to obtain a column matrix of fuzzy weights, instead of calculating fuzzy weights separately for each network parameter.

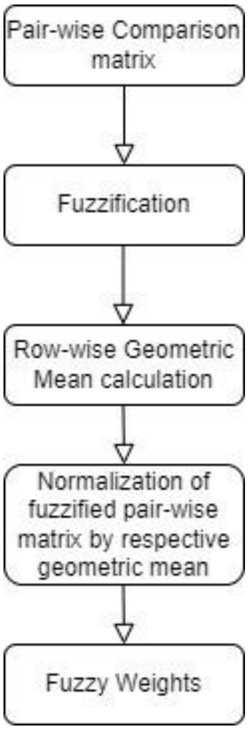

Figure 3.2 Fuzzy Weights Calculation using FAHP with geometric mean

The process of weights calculation using FAHP is repeated for all the traffic class till fuzzy weights for all traffic classes are obtained shown in Fig. 3.2. The fuzzy weights of each traffic class are taken to develop a column matrix of fuzzy weights for each traffic class which will be utilized in the handoff decision making phase.

3.2.3 Handoff Decision making using Fuzzy TOPSIS

In this phase, fuzzy weights and decision metrices are used for obtaining performance values of available networks using MCDM techniques. The comparison of different MCDM techniques is studied based on the similarity index with decision making problems [32]. Fuzzy TOPSIS proved to be more consistent in decision making with multiple attributes.

Many problems related to decision making with multiple parameters and parametric weights calculation are solves using Fuzzy TOPSIS [32], which provides the detailed view of its applications. The proposed handoff decision making algorithm uses an improved fuzzy TOPSIS for evaluating ranks of available networks by incorporating multiple traffic classes based on functionalities of the mobile node with priority levels for network parameters. Including multiple decision makers provide different perspectives to the decision-making algorithm making it more precise. The three decision makers involve in the process are:

1. Network
2. Mobile node (UGV)
3. User preference

The three decision makers extract information of network parameters from available networks and form three decision metrices. Fuzzy TOPSIS uses two group metrices as input i.e., fuzzy weight metrices of each traffic class and decision metrices from each decision maker. Based on the number of traffic classes i.e., three, and number of decision makers i.e., also three, six metrices are utilized. The steps involved in generating performance coefficient, for each network, from these two groups of metrices are:

1. Fuzzified Decision Metrices
2. Combination criteria for Weights and Decision Metrices
3. Normalized Combined Decision Matrix
4. Combined Weighted Decision Matrix
5. Best and Worst Ideal Solutions
6. Performance Coefficient Ranking

3.2.3.1 Fuzzified Decision Metrices

The decision metrices contains parametric values of available networks which are defined in the non-linguistic term or numeric values from 1 to 5, where 1 indicates lowest level and 5 represents highest level for the parametric value. The decision metrices are fuzzified according to the criteria define in Table 3.4.

Table 3.4: Fuzzification Criteria for Decision Matrix

Numeric Value	Non-linguistic term	Fuzzy Value
1	Very Low	1, 1, 3
2	Low	1, 3, 5
3	Average	3, 5, 7
4	High	5, 7, 9
5	Very High	7, 9, 9

3.2.3.2 Combination Criteria for Weight and Decision Metrices

For further process, fuzzy weight metrices and decision metrices are combined to form combined weight matrix and combined decision matrix respectively. The combination process is based on the criteria in (3.4) – (3.7). The combined weight matrix contains all the aspects of its component fuzzy weight metrices of each traffic class.

$$FW_{ij} = (\alpha_{ij}, \beta_{ij}, \gamma_{ij}) \tag{3.4}$$

$$\alpha_{ij} = \min(\alpha_{ij}^{k}) \tag{3.5}$$

$$\beta_{ij} = \frac{1}{k} \times \sum_{1}^{k} \beta_{ij}^{n} \tag{3.6}$$

$$\gamma_{ij} = \max(\gamma_{ij}^{k}) \tag{3.7}$$

Where FW_{ij} represents the fuzzy values to combine, k represents the number of metrices and α_{ij}, β_{ij}, γ_{ij} are three membership values of a fuzzy number.

3.2.3.3 Normalized Combined Decision Matrix

The combined decision matrix is normalized under beneficial and non-beneficial parameters using (3.8) – (3.11). The beneficial parameters are required to have high values, non-beneficial parameters should have low values for a better network and vice versa. In proposed technique, beneficial network parameters are received signal strength indicator (RSSI), bandwidth (BW), and signal to interference & noise ratio (SINR), while non-beneficial network parameters include network delay (ND), data loss (DL), and bit-error rate (BER).

For beneficial network parametric fuzzy values:

$$norm\_fuz\_val_{ij} = (\frac{\alpha_{ij}}{\gamma_{ij}^{*}}, \frac{\beta_{ij}}{\gamma_{ij}^{*}}, \frac{\gamma_{ij}}{\gamma_{ij}^{*}}) \tag{3.8}$$

$$\gamma_{ij}^{*} = \max(\gamma_{ij}^{k}) \tag{3.9}$$

For non-beneficial network parametric fuzzy values:

$$norm\_fuz\_val_{ij} = \left(\frac{\alpha_{ij}^*}{\gamma_{ij}}, \frac{\alpha_{ij}^*}{\beta_{ij}}, \frac{a_{ij}^*}{\alpha_{ij}}\right) \tag{3.10}$$

$$\alpha_{ij}^* = \min(a_{ij}^k) \tag{3.11}$$

3.2.3.4 Combined Weighted Decision Matrix

The product of combined fuzzy weights matrix and combined decision matrix is taken to evaluate the weighted parametric performance values of available networks. The obtained matrix is termed as combined weighted decision matrix. The order of combined fuzzy weight matrix and combined decision matrix are 1 × n and m × n respectively, where n is the number of network parameters and m is the number of the available networks. The combined weighted decision matrix is of the same order of combined decision matrix i.e., m × n therefore, fuzzy weight matrix (FWM) i.e., row matrix which contains fuzzy weights for network parameters, is multiplied to each row in combined decision matrix (CDM) to obtain respective row of combined weighted decision matrix (CWDM) using (3.12).

$$CWDM_i = CDM_i \times FWM \tag{3.12}$$

Where i is the rows of the respective matrix = 1, 2, 3, …, m.

3.2.3.5 Best and Worst Ideal Solutions

Ideal and worst solution are calculated using the best and worst values from the combined weighted decision matrix. Due to normalization based on beneficial and non-beneficial parameters, same method can be adopted for determining ideal solutions for beneficial and non-beneficial parameters. Maximum and minimum fuzzy values are selected for best and worst ideal solution respectively, by comparing the fuzzy values in their respective column of combined weight decision matrix.

Every fuzzy number has three membership values i.e., Low, Med, High. The order of comparison for finding maximum fuzzy number is high, medium, and low i.e., third position values are compared and fuzzy number having maximum third position value is selected for best ideal solution. If maximum third position value of two or more networks are equal, then second position values are compared up to first position values. The minimum fuzzy number is obtained by selecting minimum value, but the order of comparison is reversed i.e., low, medium, and high.

$$best\_ideal_j = \max(CWDM_j) \tag{3.13}$$

$$worst\_ideal_j = \min(CWDM_j) \tag{3.14}$$

where j represents the column of combined weight decision matrix = 1, 2, 3, …, n i.e., number of network parameters.

3.2.3.6 Performance Coefficient Ranking

The best and worst ideal solutions are utilized to calculate the closure coefficient value based on distance of available networks from ideal and worst solutions. Ideal solutions contain values in ideal scenarios for each network parameter. The distance between network values and ideal solution values are calculated for each network parameter i.e., separately for best and worst ideal solutions. Using (3.15), the distance between two fuzzy numbers can be calculated.

$$d_{ij} = \sqrt{\frac{1}{3} \times ((a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2)} \tag{3.15}$$

where (a_1, b_1, c_1) represents positive fuzzy number from ideal solutions and (a_2, b_2, c_2) represents fuzzy number from available networks.

Two matrices are formed using the distance formula, one for the distance calculated from best ideal solution and other for the distance from worst ideal solution. Each matrix is of the order m × n, where m is the number of available networks and n is the number of network parameters.

Row wise summation is taken for both metrices and total distance from best and worst ideal solutions are determined which result in two column metrices with each entity representing total distance value for each available network using (3.16).

$$td\_best = \sum_1^j d\_best \tag{3.16}$$

$$td\_worst = \sum_1^j d\_worst \tag{3.17}$$

where j = 1, 2, 3, …, no. of network parameters.

Performance coefficient (PC) value is calculated using (3.18), which represents the performance value of each network. Distances from both best and worst ideal solutions are incorporated in evaluating performance coefficient.

$$PC_i = \frac{td\_best_i}{(td\_best_i + td\_worst_i)} \tag{3.18}$$

Where i represents the network identity = 1, 2, 3, …, number of available networks.

The overall working flowchart of proposed handoff decision making using fuzzy TOPSIS is shown in Fig. 3.3.

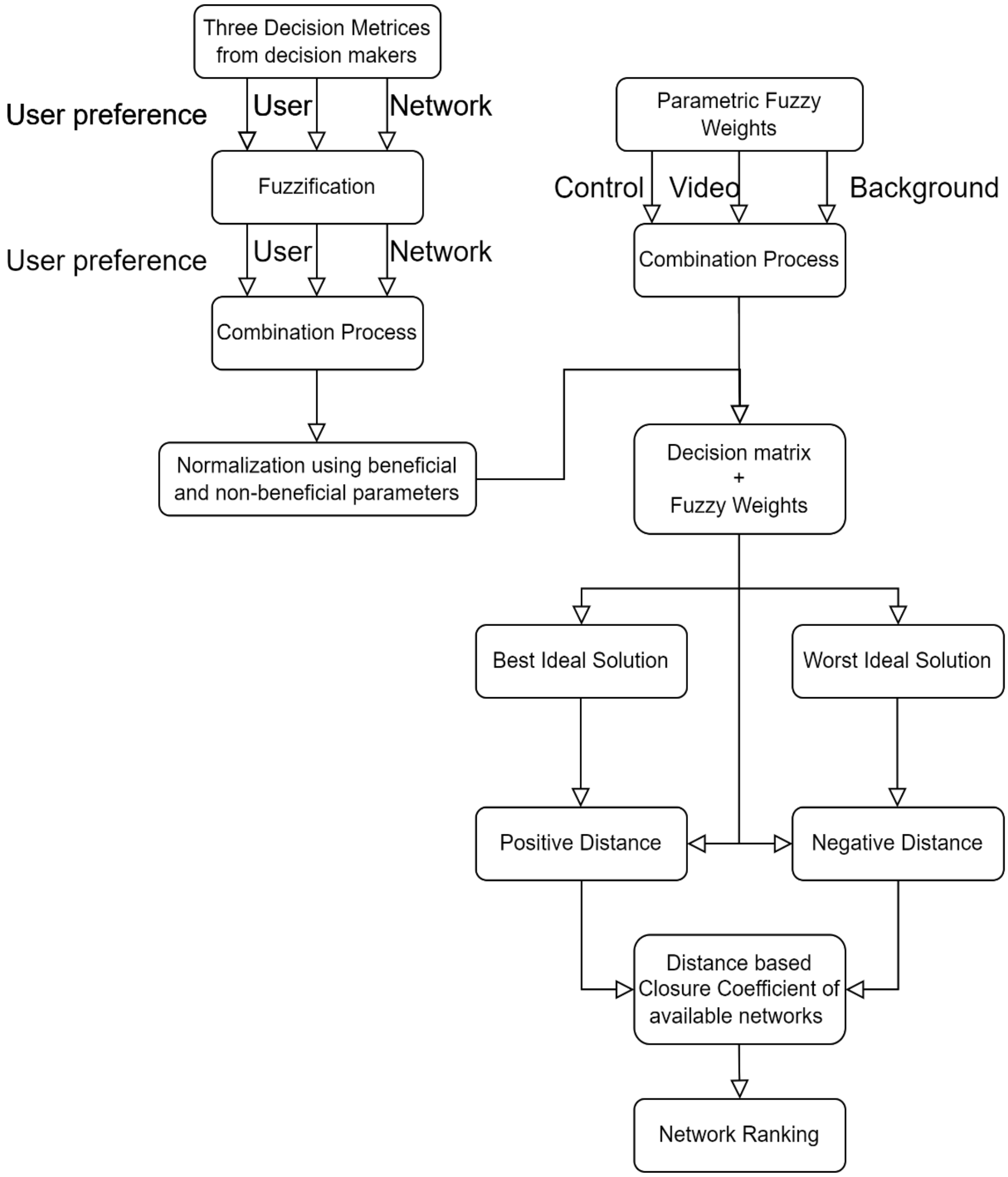

Figure 3.3 Proposed Handoff Decision Making using Fuzzy TOPSIS

The performance coefficient value of networks is compared to each other for generating network rankings. Higher rank is assigned to network with higher performance value.

3.3 Proposed Handoff Criteria

The handoff criteria decides whether a handoff is required or not based on the collected information related to network parameters and performance value of the network.

3.3.1 Handoff Criteria-I

To improve QoS and reduce power consumption by avoiding ping-pong effect and decreasing number of unnecessary handoffs, proposed handoff criteria use difference in the current and best performance values. The difference is compared to a set threshold and handoff executed when the condition in (3.19) is met.

$$PC_{best} - PC_{current} > set\_threshold \qquad (3.19)$$

The flowchart in Fig. 3.4 shows the working of handoff criteria, according to which no handoff occurs when the difference between best and current performance coefficient value is less than set threshold.

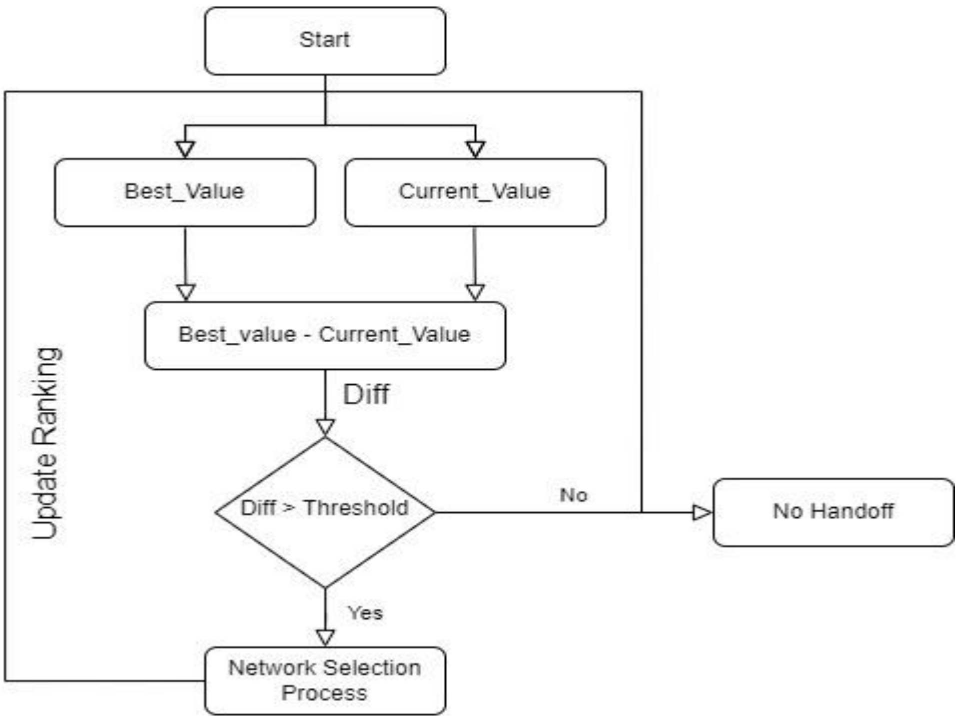

Figure 3.4 Proposed Handoff Criteria-I

The steps involved in handoffs are:

- Gathering information related to network parameters.
- Performing handoff decision making to generate performance coefficient values.
- The best and current coefficient values are monitored by the handoff criteria.
- If the difference between performance coefficient values of best and current network is greater than set threshold, then handoff is executed.
- If the difference is less or equal to set threshold, then handoff does not occur.

Utilizing handoff criteria-I was not effective in dealing with handoffs with lower performance values as discovered in experimentation section of the research. To improve the handoff capability in lower performance values, an improved handoff criteria is proposed.

3.3.2 Handoff Criteria-II

For handling lower performance values percentage difference is adopted for comparison. With the percentage criteria for comparison, handoff in lower performance values can be improved and network quality of service becomes better then handoff criteria-I. The percentage difference of performance values is calculated using (3.20).

$$\frac{PC_{best} - PC_{current}}{PC_{best}} > set\_threshold \qquad (3.19)$$

The overall working is the same as handoff criteria-I with the addition of percentage difference as the parameter for comparison which can introduce flexibility in the handoff criteria. The proposed handoff criteria-II uses percentage difference of performance values to compare with threshold to include benefits of both techniques in initiating handoff. Due to the percentage criteria, necessary handoffs in early phases will not be neglected and work efficiently in later phases. Fig 3.5 provides the flow chart of handoff criteria-II.

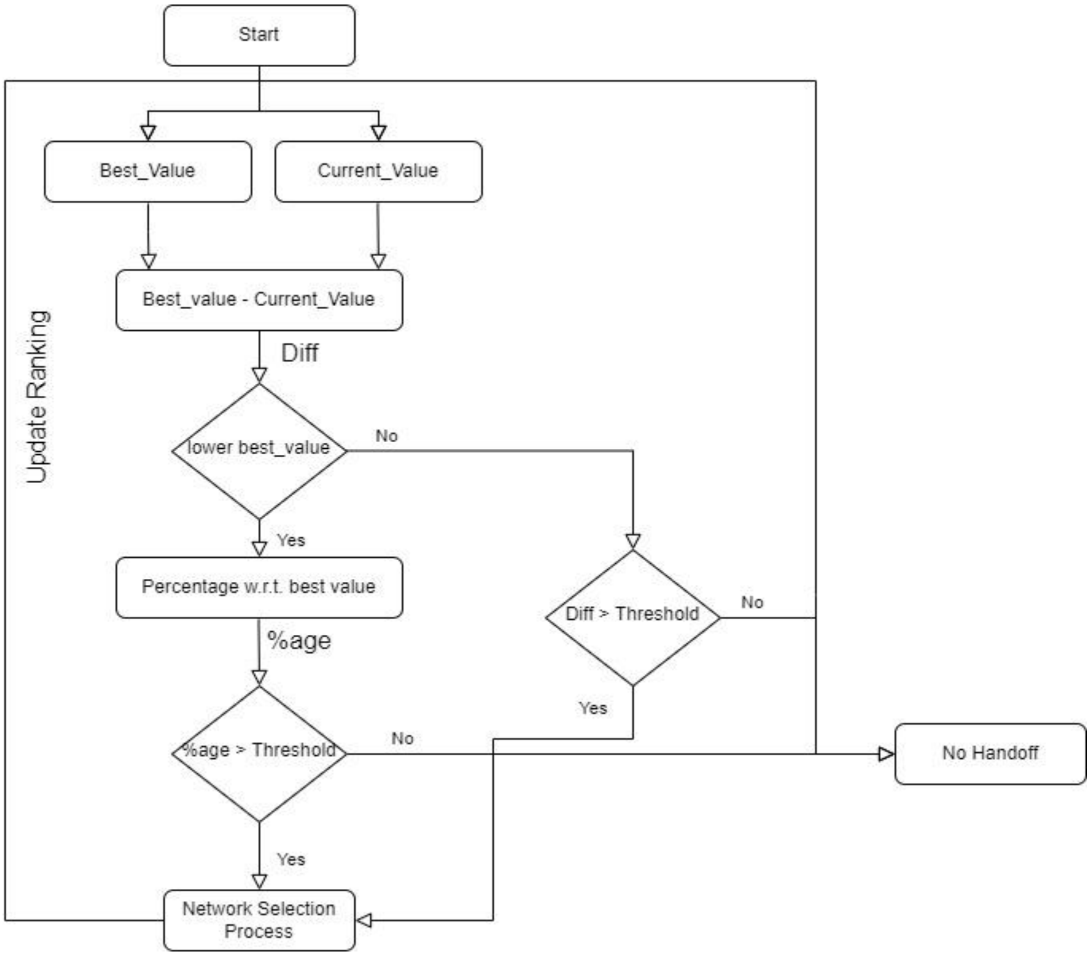

Figure 3.5: Proposed Handoff Criteria-II

The key steps in handoff criteria-II include:

1. Gathering information related to network parameters.
2. Performing handoff decision making to generate performance coefficient values.
3. The best and current coefficient values are monitored by the handoff criteria.
4. If the percentage difference between performance coefficient values of best and current network is greater than set threshold, then handoff is executed.
5. If the percentage difference is less or equal to set threshold, then handoff does not occur.

3.4 Implementation of Wireless Distribution System in Communication system of UGV

In addition to proposed handoff technique, a communication system for UGV is developed using wireless distribution system (WDS) to induce handoff capabilities and network extension in existing communication system as described in Annexure-1.

Simulation is done on enterprise network simulating platform (eNSP) by Huawei and implemented on existing UGV communication system for real time analysis. The results are discusses based on the handoff behavior and switching delay according to environmental conditions.

Chapter 4:
Simulation & Experimentation

This chapter provides experimental details and simulation environment for proposed handoff management technique using fuzzy TOPSIS for handoff decision making. At start, proposed handoff management technique, with weights calculation using FAHP followed by handoff decision making using fuzzy TOPSIS, is tested in MATLAB as simulation platform. To run the simulation, priority criteria under different traffic classes mentioned in previous chapters with network information related to selected network parameters are provided. Different phases and their result aspects are discussed. In the end, proposed handoff criteria are experimented by varying performance value of best available network to observe the number of unnecessary handoffs and other performance degradation factors.

4.1 Simulation of Proposed Handoff management technique

The proposed handoff algorithm is run on a simulated environment using MATLAB R2022b. The priority criteria defined in table 3.1 is used to form three pair-wise comparison metrices for control traffic classes shown in table 4.1. The formation of pair-wise comparison matrix is pre-requisite step in simulation.

Table 4.1: Pair-wise comparison matrix for Control Traffic class

Control	RSSI	BW	SINR	Delay	PL	BER
RSSI	1	5	5	5	3	3
BW	1/5	1	1/3	1/3	1/5	1/5
SINR	1/5	3	1	1/3	1/5	1/5
Delay	1/5	3	3	1	1/3	1/3
PL	1/3	5	5	3	1	1/3
BER	1/3	5	5	3	3	1

The matrix is formed by comparing network parameters with each other and by repeating the same steps pair-wise comparison matrix is formed given in table 4.2 to 4.3.

Table 4.2: Pair-wise comparison matrix of Video class

Video	RSSI	BW	SINR	Delay	PL	BER
RSSI	1	1/3	3	1/3	1/3	3
BW	3	1	5	3	3	7
SINR	1/3	1/5	1	1/5	1/3	3
Delay	3	1/3	5	1	5	5
PL	3	1/3	3	1/5	1	3
BER	1/3	1/7	1/3	1/5	1/3	1

Table 4.3: Pair-wise comparison matrix of Background class

Background	RSSI	BW	SINR	Delay	PL	BER
RSSI	1	3	5	7	7	7
BW	1/3	1	3	7	5	7
SINR	1/5	1/3	1	3	3	5
Delay	1/7	1/7	1/3	1	3	5
PL	1/7	1/5	1/3	1/3	1	3
BER	1/7	1/7	1/5	1/5	1/3	1

Each pair-wise comparison matrix is utilized in determining fuzzy weights of its respective traffic class. The FAHP algorithm is run in MATLAB using three user defined function for fuzzification, geometric mean calculation and weights calculation. The fuzzy weights obtained depends on the developed pair-wise comparison metrices which is dependent on the network parameter, their relations with each other and their importance level in each traffic class. The process is not only limited to number of traffic classes i.e., single to multiple traffic classes can be used to effectively generate fuzzy weights. The fuzzy weights obtained from each traffic classes are shown in table 4.4. The combined fuzzy weights are also shown for comparison with individual fuzzy weights. Using fuzzy based AHP for weights calculation and decision making provides certain criteria which aids in effective combination of fuzzy weights.

Table 4.4: Fuzzy weights for each Traffic class

Traffic Class	RSSI	BW	SINR	Delay	PL	BER
Control	0.2462, 0.3921, 0.6038	0.0251, 0.0377, 0.0616	0.0355, 0.0544, 0.0872	0.0575, 0.0930, 0.1553	0.1097, 0.1731, 0.2822	0.1551, 0.2497, 0.3991
Video	0.0621, 0.1027, 0.1782	0.2368, 0.3862, 0.6054	0.0384, 0.0600, 0.1000	0.1756, 0.2757, 0.4366	0.0821, 0.1360, 0.2246	0.0259, 0.0394, 0.0661
Background	0.3128, 0.4489, 0.6330	0.1842, 0.2703, 0.3988	0.0844, 0.1297, 0.1994	0.0507, 0.0739, 0.1097	0.0335, 0.0497, 0.0776	0.0197, 0.0275, 0.0407
Combined	0.0621, 0.3146, 0.6330	0.0251, 0.2314, 0.6054	0.0355, 0.0814, 0.1994	0.0507, 0.1475, 0.4366	0.0335, 0.1196, 0.2822	0.0197, 0.1055, 0.3991

The handoff decision making algorithm utilize combined fuzzy weights along with three decision metrices which contain network information under defined criteria from three decision makers i.e., network, mobile, user-preference. The decision makers give scores to each available networks based on their parametric information received. The decision metrices for four available networks is shown in table 4.5 to table 4.7.

Table 4.5: Decision Matrix for Network

Network	RSSI	BW	SINR	Delay	PL	BER
Network_1	3	5	3	4	4	3
Network_2	4	5	4	3	4	4
Network_3	5	3	5	2	5	4
Network_4	2	3	2	1	2	1

Table 4.6: Decision Matrix for Mobile node

Mobile node	RSSI	BW	SINR	Delay	PL	BER
Network_1	4	5	5	4	5	4
Network_2	4	4	5	3	4	3
Network_3	5	3	3	1	3	3
Network_4	2	3	3	1	3	2

Table 4.7: Decision matrix for User-preference

User	RSSI	BW	SINR	Delay	PL	BER
Network_1	3	4	4	4	4	4
Network_2	4	3	3	3	3	3
Network_3	4	3	2	2	1	2
Network_4	1	2	1	1	1	1

The decision metrices are the foundation of best and worst ideal solutions. The ideal solutions mostly depend on decision metrices or to be precise, combined decision matrix. The numeric method is adopted to combine fuzzy numbers. Table 4.8 represents the ideal solutions obtained from combined decision matrix. Although the ideal solutions are obtained after the normalization step which removes the concept of beneficial and non-beneficial parameters from decision matrix.

Table 4.8: Best & Worst Ideal Solution

Ideal Solution	RSSI	BW	SINR	Delay	PL	BER
Best	0.0345, 0.2913, 0.6330	0.0140, 0.2143, 0.6054	0.0118, 0.0633, 0.1994	0.0169, 0.1475, 0.4366	0.0048, 0.0399, 0.2822	0.0039, 0.0633, 0.3991
Worst	0.0069, 0.0816, 0.3517	0.0028, 0.1114, 0.4709	0.0039, 0.0271, 0.1551	0.0056, 0.0211, 0.0873	0.0037, 0.0156, 0.0564	0.0022, 0.0167, 0.1330

Four selected networks are ranked using fuzzy TOPSIS using ideal solutions to evaluate performance value. The ranking from fuzzy TOPSIS shows that network_3 is most suitable for handoff and is compared to traditional TOPSIS to show similarities and dissimilarities in handoff decision making. The performance values from both techniques are shown in table 4.9.

Table 4.9: Network Performance values

Network-ID	TOPSIS		Fuzzy TOPSIS	
	PV	Rank	PV	Rank
Network_1	0.3560	4	0.4688	3
Network_2	0.4258	3	0.5819	2
Network_3	0.7996	1	0.6589	1
Network_4	0.5996	2	0.4119	4

The values in table 4.9 are essential in handoff decision criteria to perform handoff in different environmental conditions and avoid performance degradation effects. The handoff decision making using fuzzy TOPSIS is simulated using proposed handoff criteria in MATLAB R2022 and experiments are performed to test the technique and proposed handoff criteria for number of unnecessary handoffs and ping-pong effect.

4.2 Experimentation

The proposed handoff criteria use best performance value and compare it with current performance value of the network. The varying maximum performance value is used to test the behavior of proposed handoff criteria and determine its capability in reducing the unnecessary handoffs and avoiding ping-pong effect. Multiple threshold values are used to evaluate the number of handoffs in the defined scenario for optimization of handoff criteria.

Utilizing the proposed handoff criteria, handoff is initiated when employed performance value is less than best performance value with the difference of set threshold. Fig. 4.1 illustrate the behavior of handoff initiation for an interval where best and current performance value are represented by curves.

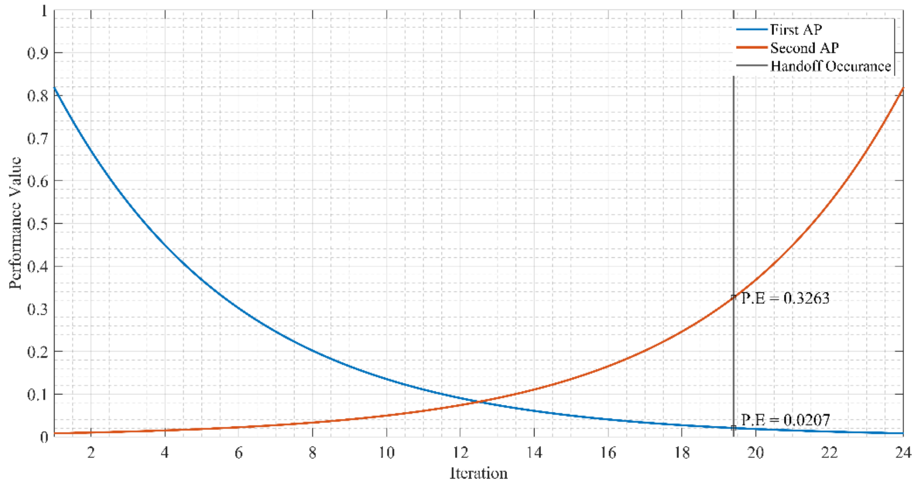

Figure 4.1: Handoff Occurrence between two APs

For handoff criteria-I, handoff is initiated when the difference in performance value is greater than set threshold i.e., 0.3 in given scenario. For handoff criteria-II, percentage of difference of performance values is observed to be greater than set threshold. The threshold value can be varied to improve the quality of service and mobility.

The next section discusses the experiments perform to improve the QoS by reducing the number of unnecessary handoffs by suitable threshold value and avoiding ping-pong effect.

4.2.1 Experiment for Handoff Reduction

This experiment is designed to test the handoff reduction capability of proposed handoff criteria by introducing varying performance values. The best performance value is varied in a simulated environment to observe the handoff occurrence in the network. The network is expected to switch its connection when the condition of handoff is satisfied. With the pre-defined signal of best performance value, several handoffs are expected which should be increased or decreased based on set threshold.

4.2.1.1 Handoff Criteria-I

In this experiment two values are observed, one is current performance value and other is best performance value. The performance values of other networks besides best value are not essential in this case. The half of sinusoidal wave signal is utilized to represent the varying nature of best performance value while the current performance value is updated whenever a handoff occurs. The experiment is simulated to test handoff criteria-I. Fig 4.2 shows the result obtained from the experiment using different threshold values.

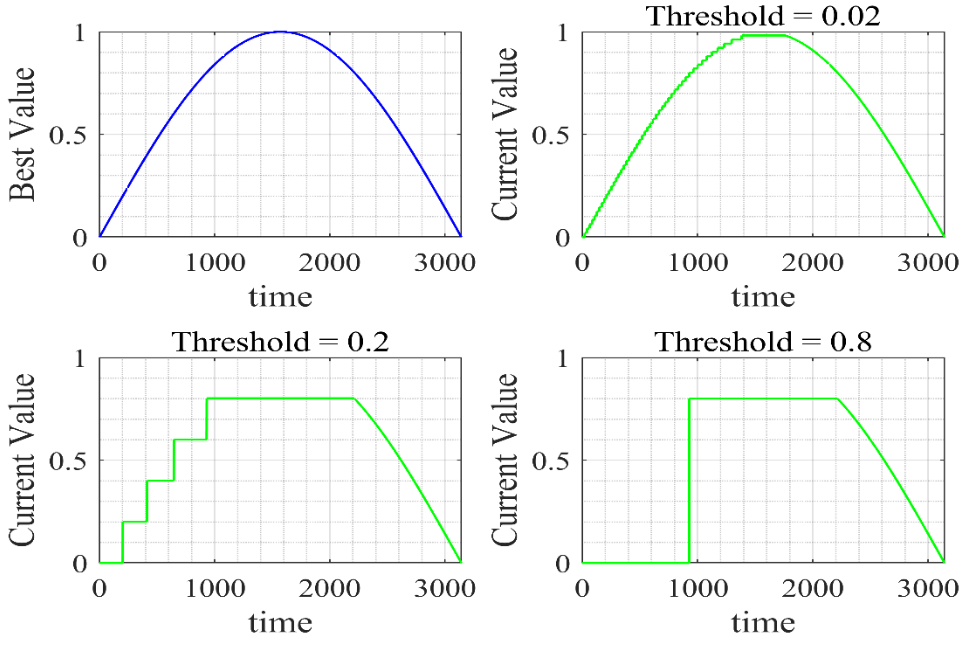

Figure 4.2: Handoff behavior of Handoff criteria-I for different thresholds

Fig. 4.2 explains that at smaller threshold values the number of handoffs increases and handoff occur even when the system is running optimally or difference between best and current network's performance is not that great. While at higher threshold values handoffs are so much reduced that handoff occurs very late. Since the maximum performance value can be at most 1, so the range of threshold is defined as 0 to 1.

To evaluate a threshold value which provides reduction in unnecessary handoffs while giving swift response to the system, handoff criteria-I is tested for multiple threshold value ranging from 0.01 to 0.9.

4.2.1.2 Handoff Criteria-II

The handoff criteria-II is tested with same varying sinusoidal curve of best performance value to observe its handoff behavior in multiple ranges of performance values. Fig. 4.3 shows experimental results of handoff criteria-II under different threshold values. The steps or vertical lines in the plots shows the occurrence of handoff in the network.

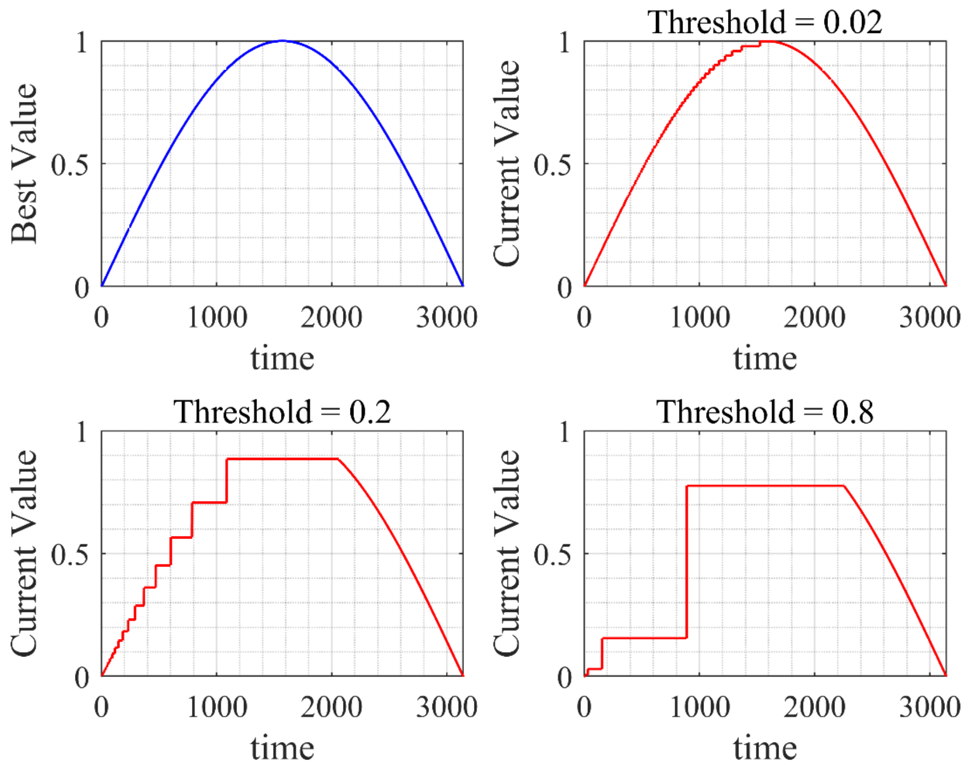

Figure 4.3: Handoff behavior of Handoff Criteria-II at different thresholds

Utilizing handoff criteria-II provides greater handoff performance and network selection at higher thresholds. Since handoff is required when a network performance value decreases from high to medium level and best performance value is higher than current performance value from a large margin. The task can be effectively handled by the handoff criteria-II and can also stimulate handoff at lower best performance values as shown in different sections of Fig 4.3. By comparing the top left graph with other plots shows that handoff criteria-II was able to initiate handoff for lower performance values at high thresholds which was not the case in handoff criteria-I.

From this Experiment it is observed that unnecessary handoff can be reduce by suitable selection of threshold value. Decreasing the threshold value from a certain limit can increase the unnecessary handoffs while increasing the threshold value from a certain limit can treat the unnecessary handoff but can also deprive the ability to handoff from the network. Handoff Criteria-I and II have shown different behavior in managing handoff in networks with lower performance values.

4.2.2 Experiment for Handoff Response Time

This experiment is performed to test handoff criteria in a network environment where two APs are present. The environment is set to obtain different performance values from APs when mobile node is roaming. Along the path, AP_1 maintains its performance value to a constant while performance value of AP_2 varies. Initially UGV or mobile node is connected to AP_1. This experiment is performed to observe handoff management of both handoff criteria under different threshold values and their handoff performance.

4.2.2.1 Handoff Criteria-I

Handoff criteria-I uses difference of performance values for comparison with threshold. At lower performance values handoff criteria-I fails to initialize the handoff even when the difference between best and current performance value was not negligible as shown in the previous experiment. While at high thresholds to reduce the unnecessary handoffs, handoff criteria-I was not able to handoff and remained connected to the previous access point which is tested in this experimentation and shown in Fig. 4.4 and Fig. 4.5.

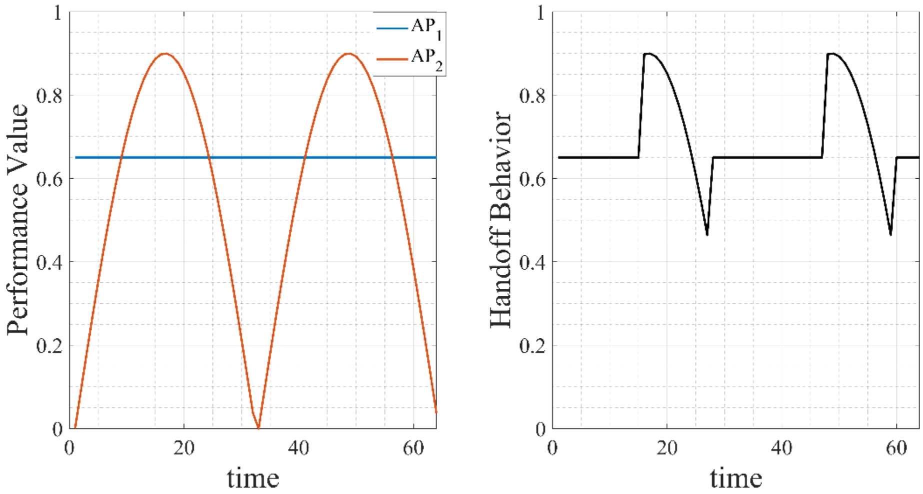

Figure 4.4: Handoff behavior of Handoff Criteria-I for Exp-2 at threshold 0.24

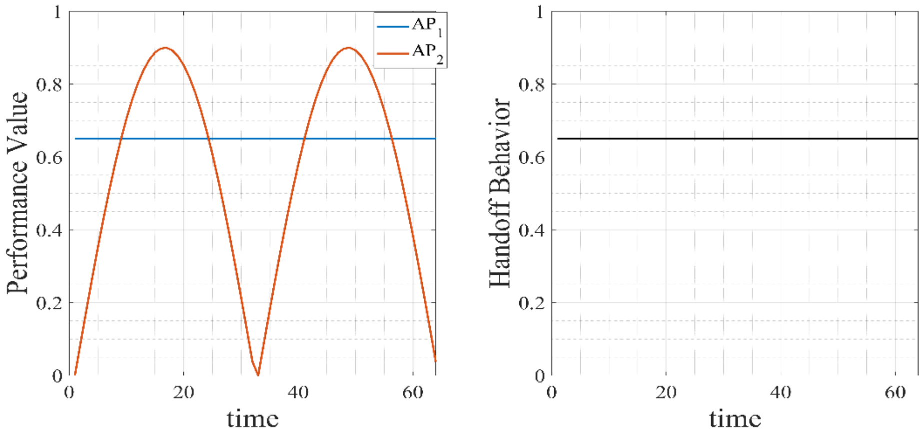

Figure 4.5: Handoff behavior of Handoff Criteria-I for Exp-2 at threshold 0.25

Using handoff criteria-I in the scenario defined in the experiment for handoff response time at threshold 0.24, mobile node was able to switch its access point, but the execution was delayed, and no handoff is observed if threshold 0.25 is utilized as in Fig. 4.5. Which limits the range of working threshold for handoff criteria-I for the given network environment.

4.2.2.2 Handoff Criteria-II

Handoff criteria-II uses difference percentage as comparative parameter with the threshold which diminishes the problem of handoff in lower performance values in handoff criteria-I as explained in experiment for handoff reduction. This test is performed to identify handoff behavior at higher threshold values to reduce the unnecessary handoffs. The limitation of handoff criteria-I is observed in experiment. The performance of handoff criteria-II is monitored in this experiment and Fig. 4.6

shows the working of handoff criteria-II in given conditions with much higher threshold than handoff criteria-I.

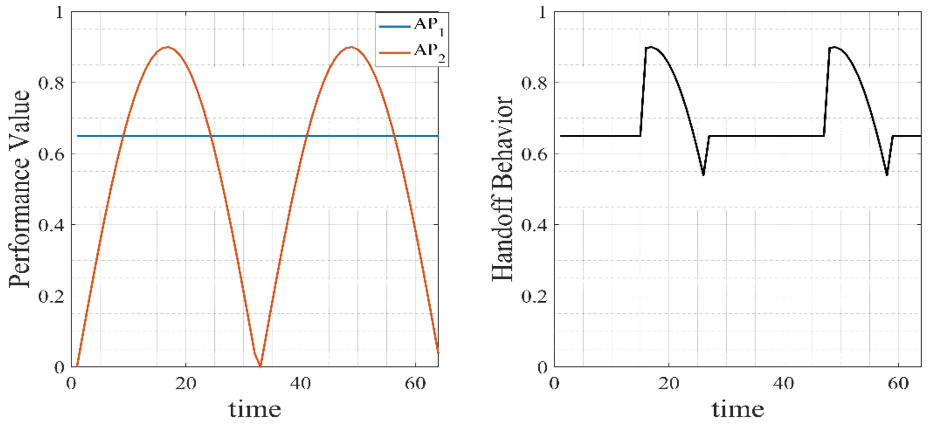

Figure 4.6: Handoff behavior of Handoff Criteria-II for Exp-2 at threshold 0.38

The handoff criteria-II can perform at threshold values 0.25 and can is observed to give results up to threshold value 0.38. Handoff results from experiment for handoff response time with handoff criteria-II using threshold value as 0.38 is shown in Fig. 4.6.

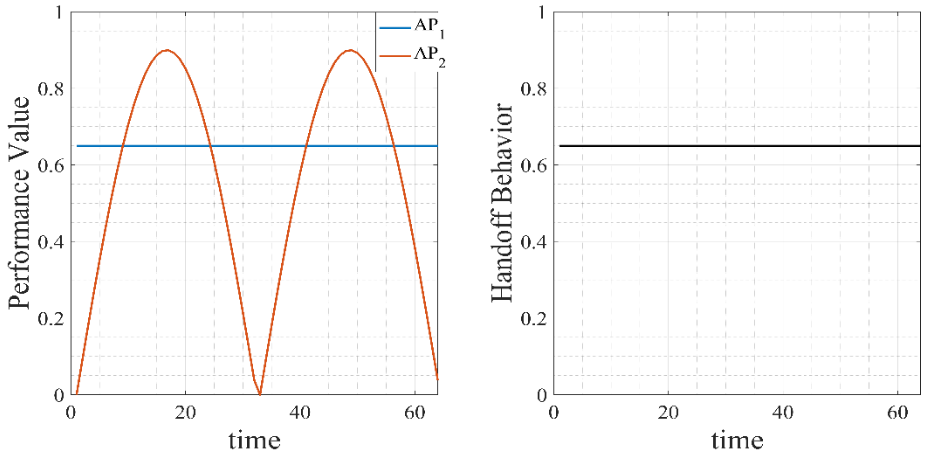

Figure 4.7: Handoff behavior of Handoff Criteria-II for Exp-2 at threshold 0.39

Fig 4.7 illustrates that handoff behavior of handoff criteria-II is not satisfactory at threshold 0.39. Handoff Criteria-II could not initiate handoff which limits the threshold range to 0.39.

It is observed in both cases that threshold value plays an important role in the handoff behavior and QoS of the network. Handoff criteria-I is observed to be effective below the 0.25 threshold value while handoff criteria-II was able to initiate handoff at higher threshold values i.e., 0.38. The results are discussed with more details in the next chapter.

Chapter 5: Results & Discussion

This chapter illustrates results obtained from research and experimentation. The chapter is divided into four sections i.e., parametric weights comparison, network ranking from proposed technique (Fuzzy TOPSIS) and traditional TOPSIS, results from experiment for handoff reduction, and handoff response time.

5.1 Parametric Weights Comparison

The parametric weights are obtained using proposed fuzzy AHP using priority criteria for different traffic classes. Since each traffic class has its own priority criteria and importance levels for different network parameters therefore, parametric weights of each traffic class are different from the other. Parametric weights of different traffic classes and combined parametric weights using priority criteria defined in methodology are shown in Fig. 5.1.

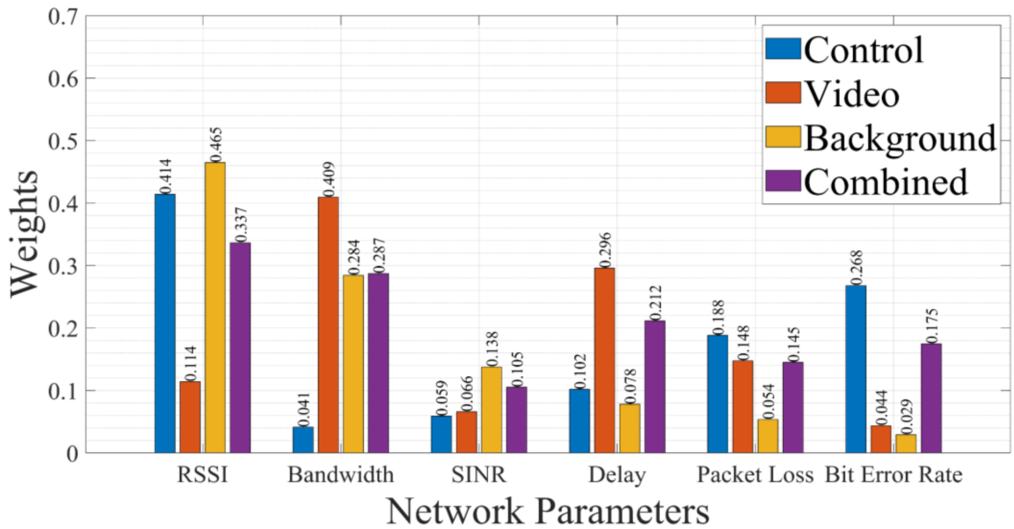

Figure 5.1: Parametric Weights for different traffic classes

RSSI was given more importance than other network parameters for control traffic class while bandwidth and network delay were given more priority in video traffic class. In background traffic class, both RSSI and bandwidth are given higher priorities than other network parameters. The parametric weights obtained from the proposed fuzzy AHP in Fig. 5.1 shows that obtained weights for each traffic class are according to the used priority criteria.

The combined parametric weights are used in handoff decision making which reflects the final importance level of each network parameters for decision making using proposed fuzzy TOPSIS based handoff technique. The final importance criteria define RSSI and bandwidth as higher priority, network delay and bit error rate are given mid-level priority, while SINR and data loss are given lower priority. Table 5.1 provides better understanding of combined parametric weights and final importance level of each network parameter.

Table 5.1: Combined Parametric Weights

Network Parameters	Combined Parametric Weights	Importance Level
RSSI	0.337	1
Bandwidth	0.287	2
Network Delay	0.212	3
Bit Error Rate	0.175	4
Packet Loss	0.145	5
SINR	0.105	6

5.2 Network Rank Comparison

Proposed handoff technique using fuzzy TOPSIS uses combined parametric weights for handoff decision making. The network information is gathered using decision metrices i.e., Network, mobile node (UGV), user-preference. The decision is made by evaluating performance value of available networks using decision metrices and parametric weights. Table 5.2 shows the performance value of available networks using proposed handoff technique.

Table 5.2: Performance Value of available networks using fuzzy TOPSIS

Network-ID	Performance Value	Network Rank
Network_1	0.3560	4
Network_2	0.4258	3
Network_3	0.7996	1
Network_4	0.5996	2

Network_3 is chosen as best available networks due to maximum performance value. The performance values vary from 0 to 1 which depends on the parametric values of respective network in decision metrices. The network rankings of fuzzy TOPSIS are compared with the results from traditional TOPSIS. Fig. 5.2 shows the bar plot to illustrate the comparison of performance values among networks and between traditional TOPSIS and proposed fuzzy TOPSIS.

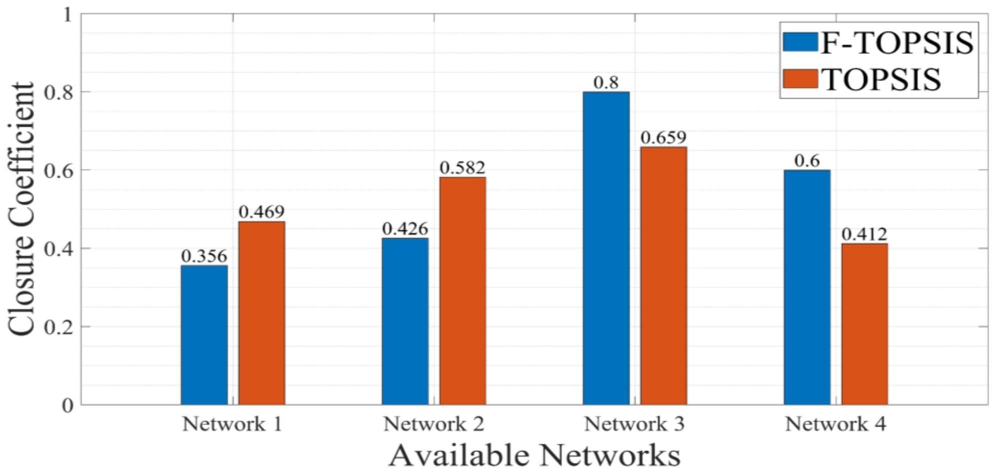

Figure 5.2: Comparison of Network Performance values of traditional TOPSIS & proposed fuzzy TOPSIS

From both techniques network_3 is chosen as best available networks due to higher performance value. Although graph shows that fuzzy TOPSIS more clearly identify best available networks from the rest and improves the handoff decision making process. It is also noted that the ranks of other networks are not the same for both techniques as from the performance values in table 5.3. The difference in network ranking or performance values of available networks is due to the matrix combination criteria defined for fuzzy TOPSIS which makes it more compatible for handling tasks with multiple metrices and network parameters which include fuzzy numbers with membership values while traditional TOPSIS uses numeric values for combination.

Table 5.3: Comparative Network Ranking based on Performance Values

Network-ID	Fuzzy TOPSIS		TOPSIS	
	Performance Value	Rank	Performance Value	Rank
Network_1	0.3560	4	0.4690	3
Network_2	0.4258	3	0.5819	2
Network_3	0.7996	1	0.6589	1
Network_4	0.5996	2	0.4119	4

5.3 Threshold vs Handoff Reduction

Experiment for handoff reduction was conducted using handoff criteria-I & II to observe the pattern of handoffs under varying thresholds. The threshold value varies from 0.01 to 0.9 while a changing signal of best performance value is passed from handoff criteria-I & II. The results obtained shows that changing the threshold value changes the number of handoffs involves in the path. Fig. 5.3 & 5.4 shows the results from the experiment for handoff reduction using 0.03 as threshold value in handoff criteria-I & II respectively.

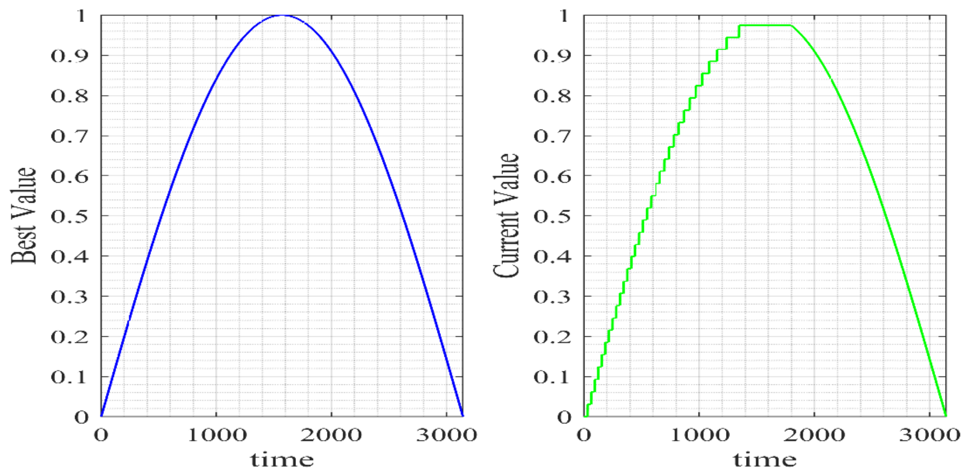

Figure 5.3: Handoffs in Handoff Criteria-I for threshold value 0.03

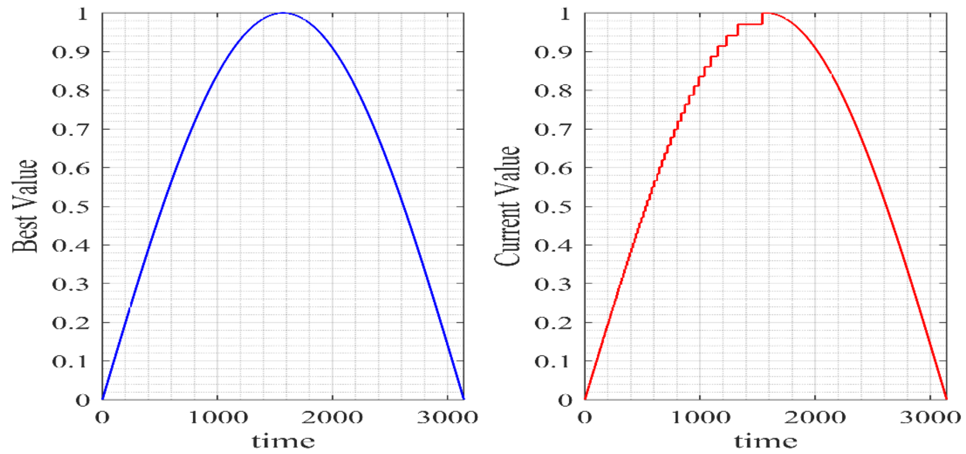

Figure 5.4: Handoffs in Handoff Criteria-II for threshold value 0.03

The left side of the graph represent changing best performance value while right side shows the response of the system. The vertical lines or steps in the right side of the graph represent the occurrence of handoff. The number of handoffs with threshold value 0.03 in handoff criteria-I are more than 30 while in handoff criteria-II number of handoffs are almost 40. The increase in the number of handoffs for handoff criteria-II is due to the usage of percentage of change in performance value instead of just taking a difference which makes it sensitive in lower performance values and may leads to ping-pong effect. Fig. 5.5 & 5.6 represents the results from same experiment but using a threshold value 0.9 to observe the number of handoffs in higher threshold values.

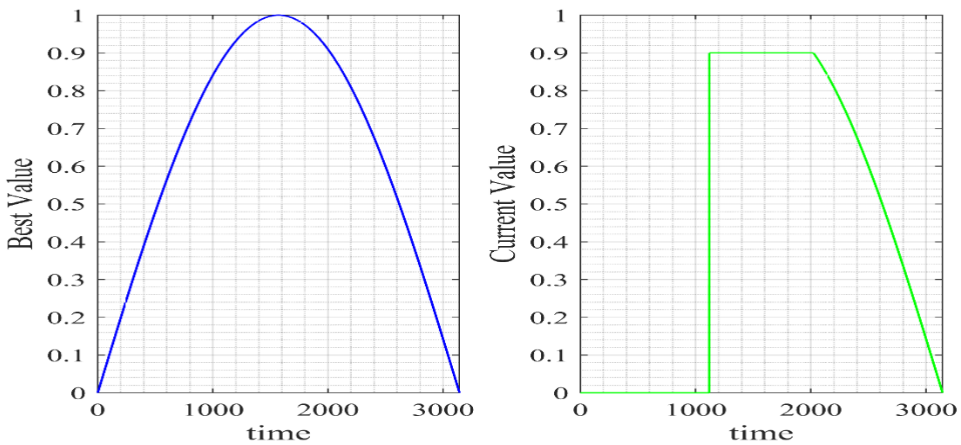

Figure 5.5: Handoffs in Handoff Criteria-I for threshold value 0.9

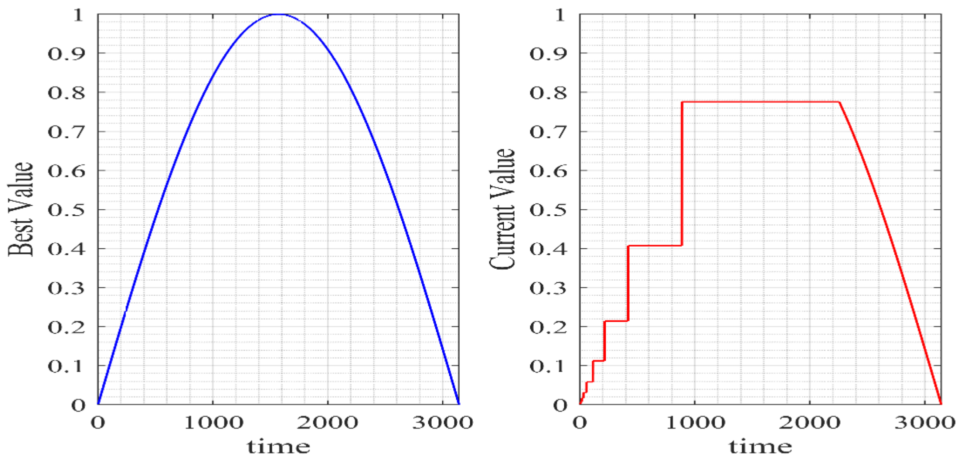

Figure 5.6: Handoffs in Handoff Criteria-II for threshold value 0.9

At high threshold value, number of handoffs for handoff criteria are significantly reduced and ping-pong effect can be avoided but due to large threshold value, in some cases no handoff occurs even when a potentially better network is available. To understand the tradeoff between number of handoffs and threshold values, number of handoffs under different threshold values are determined for handoff criteria-I & II. Fig. 5.7 & 5.8 shows the graph between number of handoffs and threshold values for handoff criteria-I & II respectively.

For handoff criteria-I, threshold range of 0.01 to 0.1 produces large number of handoffs which affects the handoff performance, and the power usage also increases which affects battery life of mobile node. The number of unnecessary handoffs can be reduced by increasing the threshold value from 0.5 to 0.9 reduces the sensitivity of handoff criteria-I. The threshold values from 0.1 to 0.5 provides suitable performance while reducing the number of unnecessary handoffs. At lower performance values, handoff criteria-I becomes less sensitive to change in performance values.

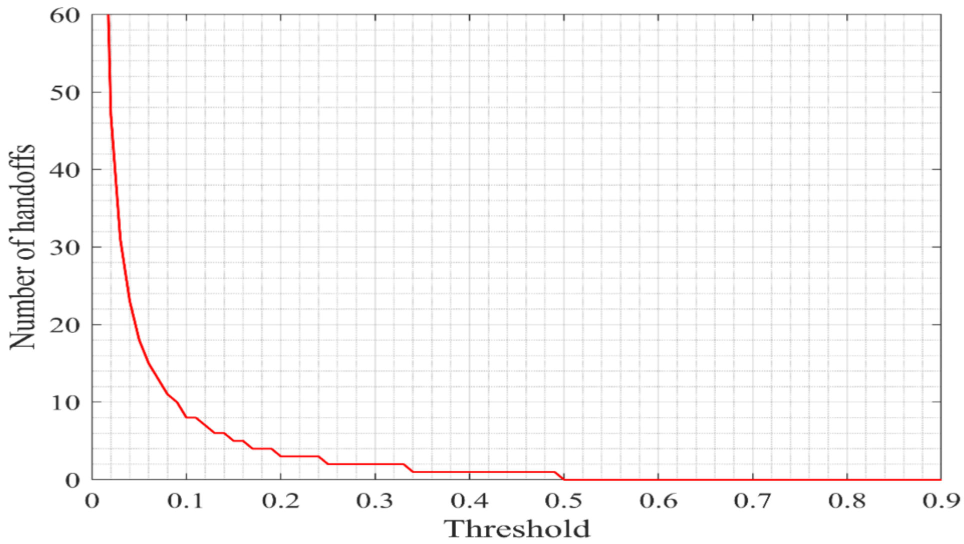

Figure 5.7: No. of handoffs vs threshold values for Handoff Criteria-I

For handoff criteria-II, lower threshold values from 0.01 to 0.6 increases the number of unnecessary handoffs. Even at high threshold values, handoff criteria-II can perform well than handoff criteria-I. Using high threshold value reduces the number of handoffs and perform well in lower network performance values. The threshold range of 0.6 to 0.9 is suitable for handoff criteria-II which can vary based on environmental conditions. Using higher threshold value reduces the chances of ping-pong effect and power consumption by reducing the number of handoffs.

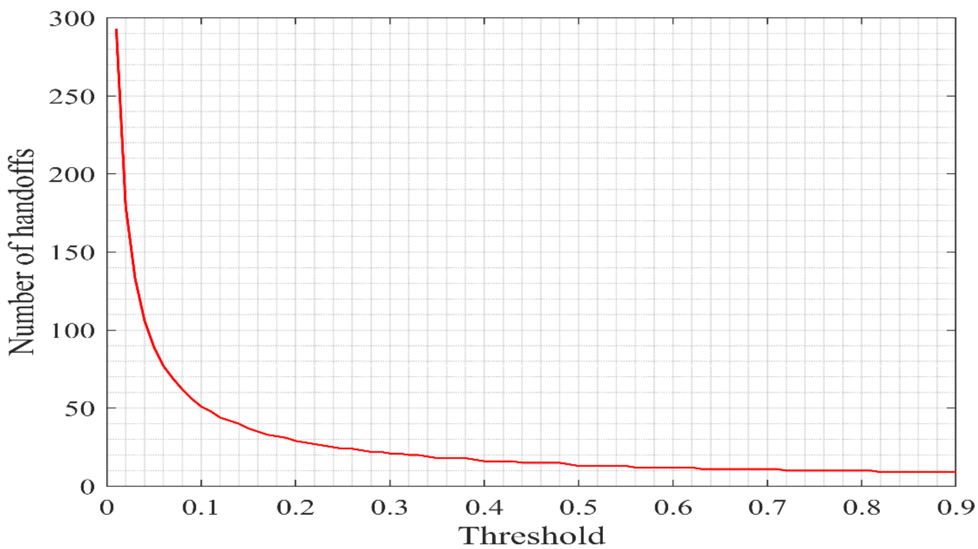

Figure 5.8: No. of handoffs vs threshold values for Handoff Criteria-II

5.4 Threshold vs Handoff Response Time

The results from the experimentation for handoff response time describes the relationship of handoff response time with the threshold value. Small response time entails quick detection of higher performance value. Fig. 5.9 & 5.10 illustrate the graph of handoff response time for handoff criteria-I & II respectively.

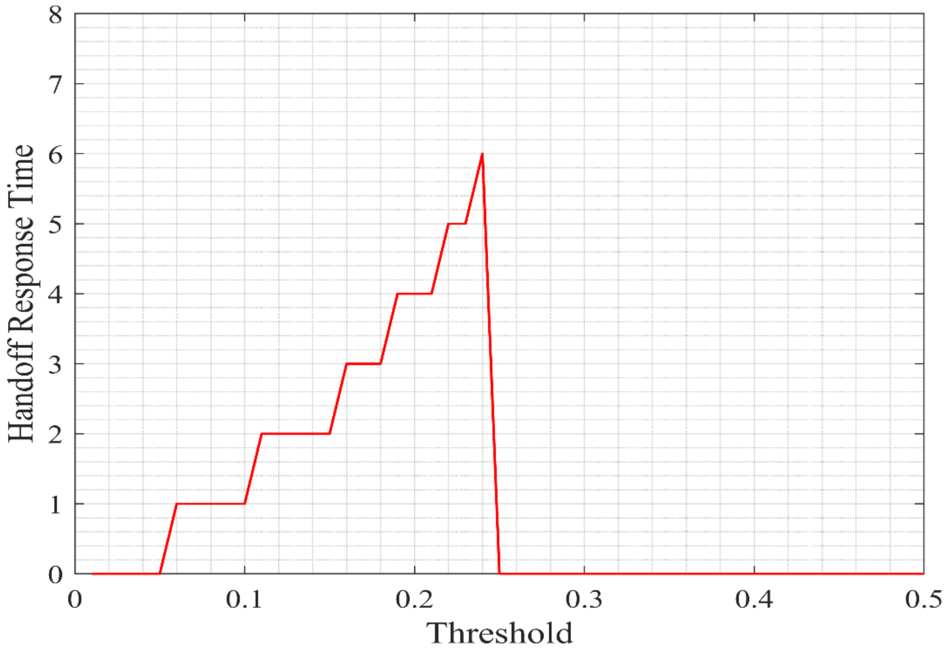

Figure 5.9: Handoff Response Time for different thresholds using Handoff Criteria-I

The increase in the threshold value shows increase in the handoff response time which makes the system less sensitive to the changes in performance values. While using small threshold increases the sensitivity of the handoff criteria making it to initiate handoff for small changes in performance value.

Maximum threshold value for the given scenario is 0.24 for handoff criteria-I and 0.38 for handoff criteria-II. Further increase in the threshold value will render the system ability to handoff just like the case of experiment for handoff reduction while reducing the threshold value will increase the number of handoffs, in the end reducing handoff performance. The selection of suitable threshold value can be done using results from both experiments to keep in check the number of handoffs and handoff response time while increasing the threshold.

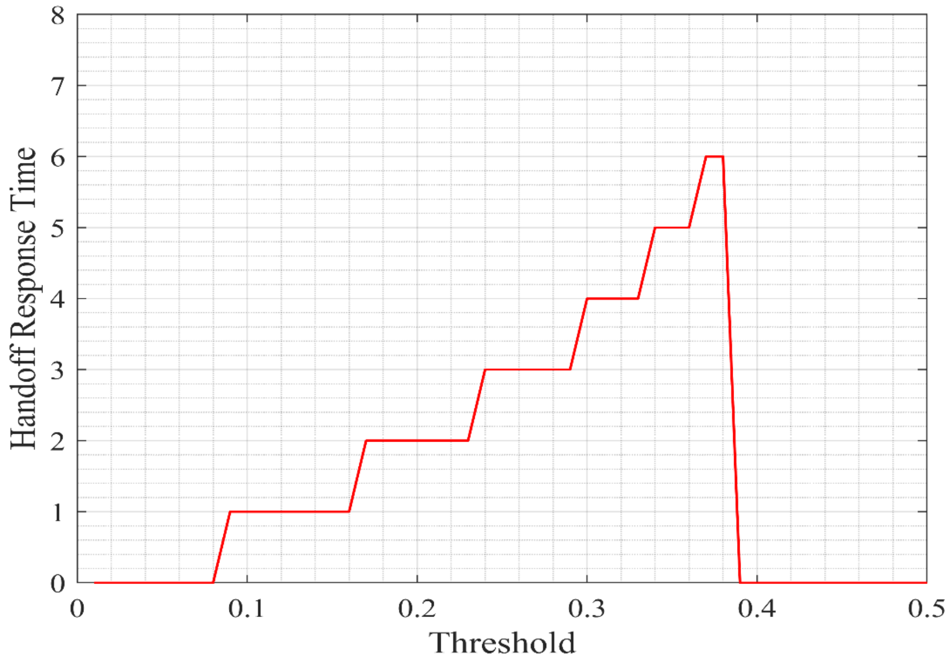

Figure 5.10: Handoff Response Time for different thresholds using Handoff Criteria-II

Conclusion

The research proposes fuzzy AHP for parametric weights calculation under different traffic classes. RSSI, bandwidth, signal to interference & noise ratio (SINR), network delay, data loss, and bit error rate are selected network parameters for three traffic classes i.e., control, video, and background. FAHP uses priority criteria based on importance level of network parameters to generate fuzzy weights. The fuzzy weights obtained are in accordance with the priority criteria. The accumulation of three decision metrices and fuzzy weight metrices increases the precision of handoff decision making while involving three traffic classes based on different required tasks of the UGV improves handoff performance. The handoff decision making algorithm uses fuzzy TOPSIS for performance evaluation of available networks by comparing distances of each available network from best and worst ideal solutions. The ranks and performance values obtained from fuzzy TOPSIS are compared with traditional TOPSIS and fuzzy based technique proved to more effective in dealing with multiple network parameters and combination of multiple weights & decision metrices. Due to different criteria for combination of metrices, ranks of available networks for fuzzy TOPSIS and traditional TOPSIS are different while both techniques can select best available network. To utilize proposed handoff algorithm for handoff decision making, two handoff criteria are proposed, one uses difference of performance values and other use percentage of difference of performance values. To test the working capability of both criteria handoff reduction and handoff response time tests are performed. For both handoff criteria, number of handoffs increases by reducing the threshold value and vice versa. To reduce unnecessary handoffs higher threshold values should be selected but increasing the threshold value beyond a certain limit causes the system to avoid handoff when needed. Even with high threshold values, handoff criteria-I cannot effectively conduct handoff involving lower performance values of networks while handoff criteria-II can detect necessary handoff even in working with lower performance values of networks. The second test is performed to study the handoff response time with varying threshold values. Both handoff criteria show different ranges of working for better handoff response time. Handoff criteria-I can conduct handoff with better response time for mid-level threshold values while handoff criteria-II can go for higher threshold values with better response time. Although increasing the threshold from a certain limit causes no handoff occurrence for both handoff criteria. The working performance of both handoff criteria changes with the environmental conditions and network information. The performance can be improved further from efficient placement of access points. From handoff reduction and handoff response time tests, handoff criteria-II shows better performance with higher thresholds with working capability in networks of lower performance values.

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Annexure-1

Implementation of WDS network technique on Teleoperated UGV for Handoff

A1.1 Background

Wireless networks use radio signals to communicate and connect with other devices. These devices can be anything including smart phones, PCs with PCI network adapters etc. Network are divided into categories such as metropolitan area network (MAN), wireless access network (WAN), local area network (LAN), personal area network (PAN) etc. MAN is formed by linking different LANs. It is a large network which provides coverage to modern city. It provides high speed and reliability. LAN mostly utilized for departments, schools, library, or small buildings. LAN is organized into multiple nodes or end devices which are governed by the base station. PANs are made for short time span. It is used to transfer files from one device to other. Usually, this type of network does not require any pre-defined structure and are much cheaper than such as Bluetooth. Everyone is moving towards fast and reliable network by using up to date hardware, 802.11ac. Utilizing latest hardware can produce remarkable results but due to network topology and unexpected conditions results deviate from the desired output. All network devices work on a specific range whether it is wired or wireless. To tackle this problem multiple network devices are linked together to form a communication network having different levels through which it can spread over large area. This type of network requires multiple base station and access points. Multiple access points work under a base station. Each base station is linked together to form a metropolitan area network. Mostly unmanned ground vehicles are appointed on a department level area. For building a communication network of UGV usually does not require that much area so adopting metropolitan network topology would increase the cost and redundancy in a network. To avoid this situation wireless distribution system is used. Wireless distribution system is a network configuration in which cables are not used as media of data transfer. The media of data transfer used are wireless signals from the APs. To establish a wireless distribution system (WDS) link between two Aps, they must be configured on same radio channels, encryption method and encryption keys. Different APs can have different service set identifiers

(SSIDs). For a WDS network, one AP is provided with a wired connection while the other can for a WDS-link with wired AP and extend the network range. In terms of connectivity of AP, WDS-link is divided into two modes.

1. WDS Bridge
2. WDS Repeater

In WDS-bridge mode, two APs form a WDS link between each other and does allow any other client or station to access the network. While in WDS-repeater mode, two APs form a WDS link and can also communicate with other devices or stations. Wireless distribution system (WDS) has two topologies or network configuration i.e.

1. WDS infrastructure
2. Mesh WDS

In WDS infrastructure, an AP2 can only receive signal from AP1, which means if AP2 is offline then AP3 will not be able to get any internet signal. It also affects the number client a network can provide services to. So, no more than five APs can be arranged in WDS infrastructure. In WDS mesh, all APs are interconnected to neighboring APs in the form of mesh. So even if one AP is damaged, other AP can take its place if it is in the range. It is expensive and requires optimize positioning of APs but can provide alternate path for connectivity if one AP is damaged. WDS network provides great flexibility and mobility.

A1.2 Methodology

The method proposed is to utilize wireless distribution system (WDS) as a network topology for the communication system of UGV. For this, multiple access points (APs) are used. Each access point is placed according to its recommended coverage, which depends on the quality of access point (AP). Access points are connected using wireless distribution system in a series, in which one access point is connected to its previous access points. The connection between APs is established either by web client service or command line interface (CLI). Most of the APs have web client service which provide graphical user interface.

Each access point is manually configured by establishing a wired connection with the computer. First access point (AP_1) acts as the base station and does not require any changes. It can work on normal configuration. The second access point (AP_2) is configured by using a computer. To log in into web client mode, user-id and password is used which is given on the back of each access point. Dynamic host configuration protocol (DHCP) server option should uncheck. In wireless settings, WDS mode is enabled. By enabling WDS mode, it asks for the media access control (MAC) address of access point to attach. If the MAC address of the first access point (AP_1) is not known, then click the survey option and select the wireless network of first access point (AP_1).

In command line interface, steps are same but utilize different sets of commands to set up a WDS-link. It also requires MAC address of each access points (APs). Simulation is done using command line interface on Huawei enterprise Network Simulator Platform (eNSP).

After establishing WDS-link between access points (APs), either wired or wireless connection is formed between controller and first access point (AP_1). Once UGV is connected to the wireless network, controller can be used to send commands or control the UGV as required. The range of the network can be increased by deploying more access points.

A1.3 Enterprise Network Simulation Platform

Enterprise Network Simulation Platform (eNSP) is used as a network simulation software. It is a graphic network simulation platform developed by Huawei. Multiple routers, servers, access controls and other devices are graphically represented and simulated in eNSP. It can simulate large and complex networks without using real devices.

A1.3.1 Features

- Graphical User Interface
- High Simulation Degree
- Connection with actual devices
- Distributed Deployment

A1.3.2 Dependencies

Enterprise network simulator platform (eNSP) requires some pre-installed software to run.

- Wincap V4.1.3

- Wireshark V2.6.6
- VirtualBox V 4.2.X – 5.2.X

A1.3.3 Flow Chart

The flow chart represents the network profiles required in an AP and AP group for WDS network. All these profiles can be set alternatively and can be changed to modify the network. Each of these profiles are configured in AC (access control) device.

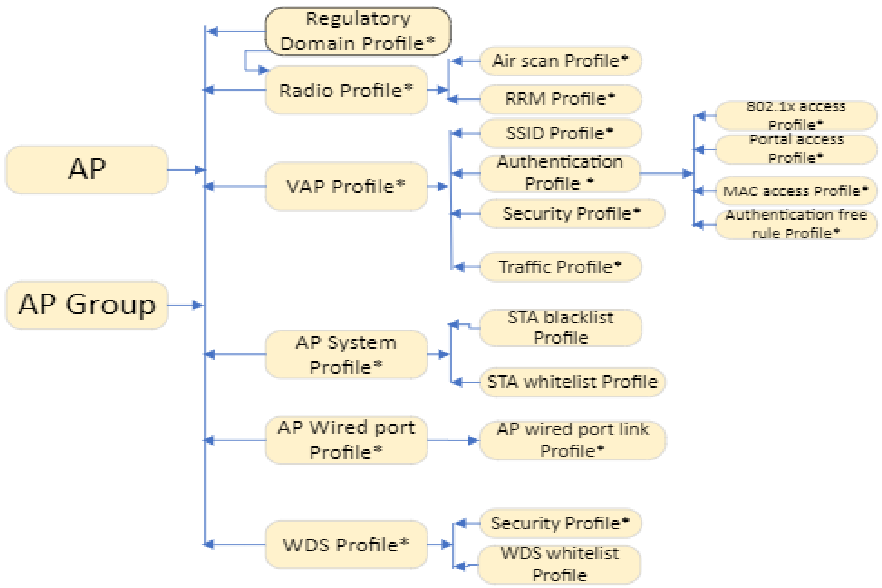

Figure A1.1: Flow chart of Network Profiles in an AP and AP group

A1.3.4 Network requirements

- AC networking mode: Layer 2 networking in bypass mode
- DHCP deployment mode:

The AC functions as a DHCP server to assign IP addresses to APs

The aggregation switch functions as a DHCP server to assign IP addresses to STAs.

- Wireless backhaul mode: Hand in Hand WDS
- Backhaul radio: 5 GHz
- Service data forwarding mode: direct forwarding

5. Configuration Roadmap

- Configure APs to go online on the AC.

a. Create an AP group and add all the APs which would have the same configurations.

b. Configure system parameters, country code and source interface to communicate with the APs.

c. Configure the authentication mode of AP to go online.

- Configure WDS services to make other APs go online through WDS link.
- Configure WLAN profile for STAs.

6. Network Planning

To configure a WDS network in eNSP, access point (AP) with two radio antennas. Each of them is programmed on corresponding WDS mode either root or leaf. For simulation, three APs are used which are assigned to their respective AP-group. The radio antenna forming WDS-link with each other are assigned to same channel and each WDS-link is assigned to different channel than the other. WPA2, PSK and AES security policies are used in WDS security profile.

A1.3.5 Network Diagram

The Figure 2 below shows the working simulation model of WDS Network. Three APs for WDS-link in a way that AP_1 form WDS-link with AP_2 using radio 1 with same channel. Second WDS-link is formed by using radio 0 of AP_2 and radio 1 AP_3 on same channel. The STA_1 represents the controller through which control signal are sent. Other two stations represent the two positions of UGV in a working environment and maintaining their connectivity.

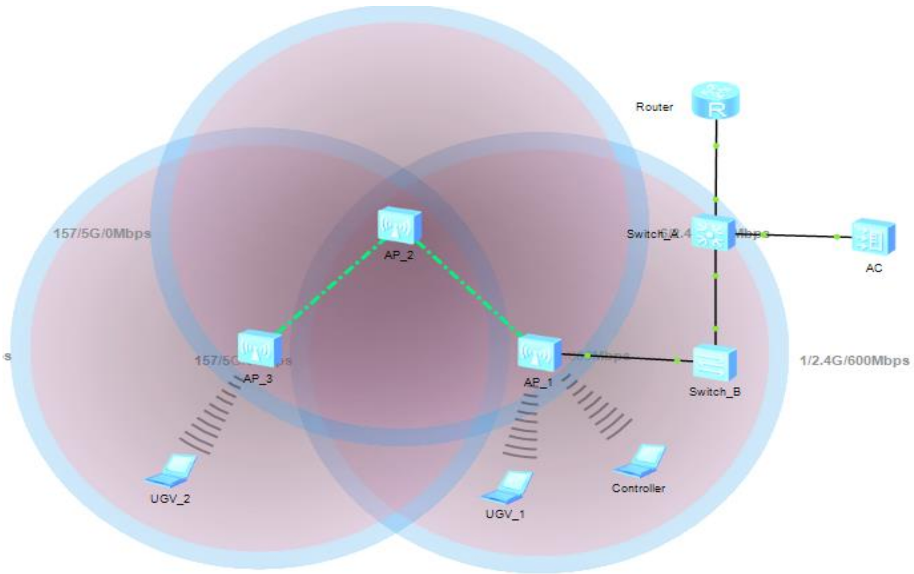

Figure A1.2: Network diagram of WDS simulation on eNSP

A1.3.6 Wireshark

Wireshark is an open-source network analyzer software which is used to capture packets in a network. Wireshark is mostly used as network troubleshooting tool, debugging, security and learning network topology while in this case, it is utilized as packet analyzer in eNSP workspace.

A1.4 Implementation

After simulating WDS-network on eNSP, it is implemented on teleoperated UGV for performance evaluation under different environmental conditions. To implement it on real time, Ubiquiti routers are selected which provides better range and connectivity in peer-to-peer networking. Selection of router is done based on the required task to be performed by them. For the performance evaluation, a network environment with two access points and one mobile node is adopted. Therefore, two sector routers and one omni router is required. For this purpose, two Ubiquiti nano-station M5 are selected as access points while Ubiquiti nano-station Rocket-M5 is selected as mobile node.

The sector routers provide coverage over specific angle i.e., 25^o to 35^o with longer range of distance while omni routers have elliptical signal band with shorter range. The network environment is developed to have a perpendicular path with one access point at the start facing the corner while second access point at the corner facing the perpendicular path as shown in the Fig. A1.3.

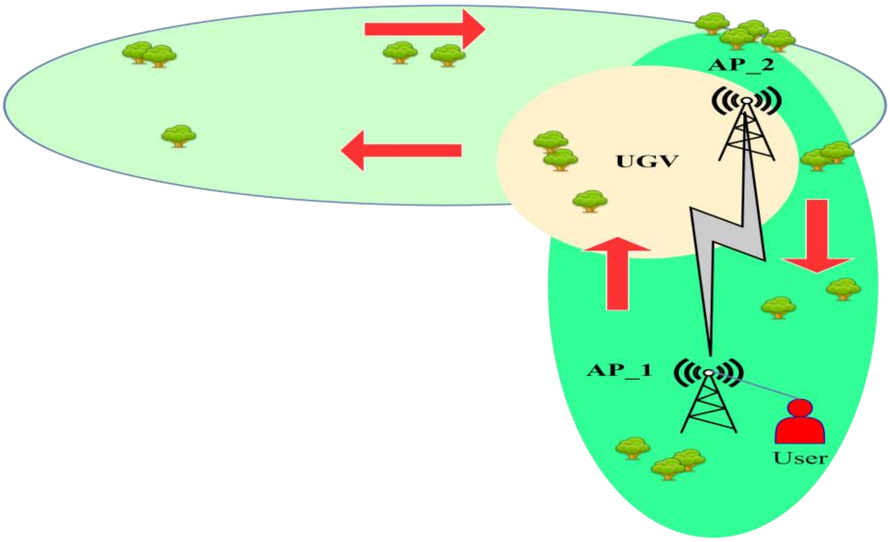

Figure A1.3: Environmental setup for WDS-network on UGV

The UGV is deployed in the coverage area while maintaining its connection to first access point. The network is built on WDS technology to provide wireless peer to peer connection between access points. NCHO based on break before make configuration are used i.e., as the UGV switches its access point when its current connection with access point breaks. Due to which placement of access points plays a vital role in networking performance.

The nano-station rocket M5 is set to station mode with SSID based connectivity. To extend the range of each ubiquity devices, antennas are used to boost the signals. The UGV is operated multiple times with different environmental conditions i.e., controlled, and uncontrolled environment. Network setup is the same in every condition. In controlled environment, UGV is deployed inside the building excluding to the factors like environmental noise, weather, and atmospheric interference while in uncontrolled environment, UGV is operated on open grounds with environmental interferences. Video feedback from attached camera on UGV is used for performance evaluation and its connectivity is monitored on web client interface of ubiquity devices. The blinking led on the control panel gives the connectivity signals based on its blinking speed. While operating UGV, handoff switching time and behavior are monitored in both environmental conditions for analysis.

A1.5 Results & Discussion

In controlled environment, due to less environmental interference and better signal distribution strong connectivity is observed from the led and video feedback. Handoff is successfully executed when the connectivity with the first access point drops from a certain level. In video and led feedback, handoff is detected by the lag and web interface of UGV-station proves the switching of access points. The handoff time observed from different iterations in controlled environment is shown in table A1.1.

Table A1.1: Handoff switching time in controlled environment

No. of Iterations	Handoff Switching Time (sec)	
	AP1 to AP2	AP2 to AP1
1	2	3
2	1	1.5
3	1.5	1
4	3	2

In uncontrolled network environment, connectivity and UGV response introduces lag due to noise and environmental interferences. The working quality of UGV is improved by adding antennas with ubiquity devices to boost signal strength. The approximate range of one ubiquity nano-station M5 with antenna boost is above 700m. The feedback and monitoring system is the same as above. The UGV follows the path in Fig A1.1 and returns to first access point. The cycle is repeated multiple times to explore its performance and handoff behavior. Table A1.2 describes the handoff delay of both direction in uncontrolled environment.

Table A1.2: Handoff switching time in uncontrolled environment

No. of Iteration	Handoff Switching Time (sec)	
	AP1 to AP2	AP2 to AP1
1	6	7
2	5	8
3	7	9
4	6	8

The handoff in controlled environment requires more time than uncontrolled environment. Controlled environment provides smooth handoff capabilities, visual and control response while uncontrolled environment provides less smoothness in video feedback.

It is also observed that even after leaving the coverage area of second access point while returning to first access point, UGV remain connected to second access point to a certain distance. The reason to this unpredictable behavior of UGV is due to the use of omni-antenna based mobile station. Since omni-antenna provide elliptical coverage area of about 300m with signal boost, it still receives connection from second access point even after entering coverage area of first access point.

A1.6 Conclusion

The implementation of wireless distribution system (WDS) to provide extended range and network switching capabilities in the communication system of UGV gives wireless peer to peer connection. The number of access points can be increased based on the required coverage area and optimization is done in the placement of access points. The break before make topology with network-controlled handoff technique avoids unnecessary handoffs and ping pong effect. The analysis shows that handoff and UGV response works better in controlled environment where there is less interference while in uncontrolled environment, multiple factors come into play and can affect the performance of communication system including handoff.

Completion Certificate

It is certified that the thesis titled "***Development of UGV Communication System using Wi-Fi Network Hopping technique***" submitted by CMS ID. 0000317544, NS Muhammad Wajid Khan of MS-2019, Mechatronics Engineering is completed in all respects as per the requirements of Main Office, NUST (Exam branch).

Supervisor: _____________

Dr. Umar Shahbaz Khan

Date: ______Dec, 2022

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS/MPhil thesis written by Mr. Muhammad Wajid Khan, (Registration No. 317544), of Department of Mechatronics Engineering/ College of Electrical and Mechanical Engineering (CEME)/ National University of Sciences and Technology (NUST) has been vetted by undersigned, found complete in all respects as per NUST Statues/Regulations, is within the similarity indices limit and is accepted as partial fulfillment for the award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Signature: ______________________________

Name of Supervisor Dr. Umar Shahbaz Khan

Date: ______________________________

Signature (HoD): ______________________________

Date: ______________________________

Signature (Dean/Principal): ______________________________

Date: ______________________________