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RECOMMENDATION

The undersigned certify that they have read and recommended to the Department of Electronics and Computer Engineering for acceptance, a thesis entitled "**Efficient Vertical Handover Decision Algorithm using Multi-criteria Metrics**", submitted by **Vandana Dhakal** in partial fulfillment of the requirement for the award of the degree of "**Master of Science in Information and Communication Engineering**".

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DEPARTMENTAL ACCEPTANCE

The thesis entitled "**Efficient Vertical Handover Decision Algorithm using Multi-criteria Metrics**", submitted by **Vandana Dhakal** in partial fulfillment of the requirement for the award of the degree of "**Master of Science in Information and Communication Engineering**" has been accepted as a bonafide record of work independently carried out by her in the department.

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ABSTRACT

The ever-increasing data and services demand of the users has been catered well by the remarkable development of the heterogeneous network. A ubiquitous seamless connection between architecturally different networks requires an efficient vertical handoff mechanism. Considering only the received signal strength (RSS) to decide when and where handover initiates is an inefficient approach to determine the target network. Multiple criteria have to be taken into account as not all the available networks have similar capacity, availability and services as that of users' requirement. In an integrated network environment consisting of WiMAX, WCDMA and WLAN, RSS method of handover is performed and multicriteria Technique for Order Preferences by Similarity to an Ideal Solution (TOPSIS) method of handover decision algorithm is analyzed. A multicriteria fuzzy rule based handover decision algorithm is developed where the number of rules for four inputs and three memberships function is reduced by using Iterative Dichotomizer 3 (ID3) method. The number of handoffs seen in fuzzy rule base algorithm is higher than in RSS and TOPSIS method but fuzzy method showed a better load balancing property in the analysis. The load balance index of fuzzy method is 25% better than RSS method and 41% better than TOPSIS method using random waypoint mobility. Using Manhattan mobility, the load balancing property of fuzzy method is 21% better than RSS method and 17% better than TOPSIS method. The percentage of blocked requests with respect to successful handoff request varies between 2.07 - 4.8%.

Keywords—Heterogeneous Network; Vertical Handover; TOPSIS Method; Fuzzy Inference System; ID3 Method; Mobility Models

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List of Abbreviations

AAS	Adaptive Antenna System
AN	Access Network
AP	Access Point
BER	Bit Error Rate
B3G	Beyond Third Generation
EIRP	Effective Isotropic Radiated Power
FIS	Fuzzy Inference System
FLC	Fuzzy Logic Control
ID3	Iterative Dichotomizer 3
IMT	International Mobile Telecommunication
ISM	Industrial, Scientific and Medical
MADM	Multiple Attribute Decision Making
MF	Membership Function
MIMO	Multiple-input Multiple-output
NLOS	Non Line of Sight
QoS	Quality of Service
RAT	Radio Access Technology
RSS	Received Signal Strength
RSSI	Received Signal Strength Indication
TOPSIS	Technique for Order Preferences by Similarity to an Ideal Solution
UMTS	Universal Mobile Telecommunication Service
VHO	Vertical Handover
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPAN	Wireless Personal Area Network

1 Introduction

Handover is said to have taken place when a mobile station switches from one set of radio resources to another set. The handover technique on the basis of whether access technology changes or not can be categorized into: i) Horizontal Handover: The handover within same access networks; ii) Vertical Handover: The handover across heterogeneous access networks or mobility between different layers. Horizontal Handover is also referred to as the Intra-Access Network (AN) handover and vertical handover also referred to as the Inter-AN handover.

The concept of heterogeneous network is introduced to satisfy the demands of varied customers for varied network resources. It consists of multiplatform networks with various radio access technologies (RATs). A mobile user may roam within these networks and accomplish the vertical handover (VHO) using single criteria, such as received signal strength (RSS). A single criteria vertical handover decision, however, is inclined to one parameter value and may not represent users' requirement. It may cause inefficient handoff, unbalanced network load, and service interruption.

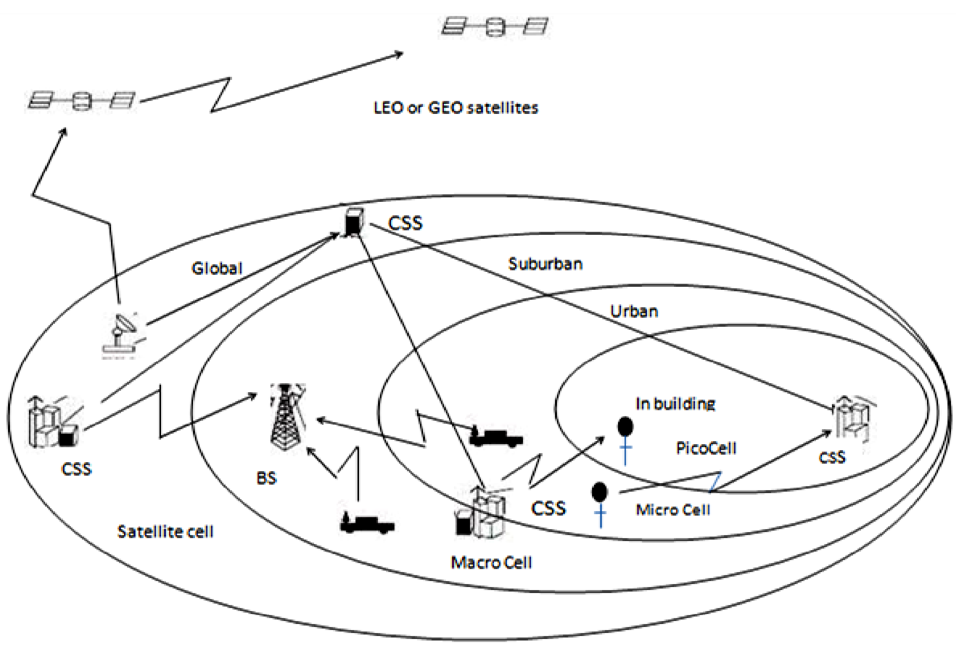


Figure 1-1 Diverse third- and fourth-generation (3G and 4G) wireless network

The demand of data rate and traffic capacity of mobile communication is growing rapidly; this necessity has been well addressed by integrating different networks at an area. In a heterogeneous network, mobility feature is essential because mobile stations must be able to roam throughout the network and able to connect to various RATs.

This switching from one station to another is based on the discovered access technologies, quality of service (QoS) constraints, operator policies, user preferences and available system capacity and utilization. An emerging issue of research is on optimizing the VHO process so as to reduce the network signaling, mobile station power loss, balancing the networks, improving the QoS and reducing the blocking probability of the networks.

The RSS method of handover decision is considered as the simplest method to decide handover but it may not have sufficient reliability because of the RSS fluctuation. Horizontal handover takes place between points of attachment in the same RAT in the border region of two cells (for example, between two neighboring base stations of a cellular network), the vertical handover occurs between points of attachment supporting different RATs (for example, between an IEEE 802.11 access point (AP) and a cellular network base station). VHO (also called intersystem handover) enables users to access several networks such as wireless local area network (WLAN), wireless municipal area network (WMAN), and wireless personal area network (WPAN) in parallel [1].

Several issues should be studied such as handover metrics, handover decision algorithms and handover management in order to achieve seamless handover [2]. The vertical handover is a complex process since it has to make the handover decision among networks that has different system properties, the decision cannot be based on only one factor (like RSS) as in the horizontal handover.

Heterogeneous networks provide more flexibility in term of service continuation and capacity to mobile users by having multi-layer networks of different wireless system and interfaces. However, in such network seamless vertical handoff across different networks becomes a challenging and crucial process. Conventional vertical handover decision algorithm uses received signal strength indicator (RSSI) as a main parameter to decide handover [3]. Next generation wireless networks need seamless handoff between different wireless networks. A suitable and efficient vertical handoff algorithm may make seamless handoff possible between all types of RATs.

The goal of beyond third generation (B3G) or fourth generation is to provide users with ubiquitous information access capabilities. A generally accepted approach for this is to integrate currently existing various wireless networks such as IEEE 802.11 WLANs, IEEE 802.16 wireless metropolitan area networks, general packet radio service, and universal mobile telecommunications systems. No single wireless network technology can simultaneously provide high bandwidth, low latency, low access cost, and wide area service to a large number of mobile users [2].

Vertical handover is one of the key technologies to support seamless connectivity across multiple wireless communication systems and guarantee QoS for the applications therein [4]. One of the challenging problems for coordination is vertical handoff, which is the decision for a mobile node to handoff between different types of networks. While traditional handoff is based on received signal strength comparisons, vertical handoff must evaluate additional factors, such as monetary cost, offered services, network conditions, and user preferences [5]. Due to the simplicity and availability of the hardware equipment required for RSS calculations, a fairly large number of studies have appeared in this area of research during the past years.

Handover mechanisms have four different phases: Handover Initiation, System discovery, Handover decision, Handover execution. Handover decision phase compares the neighbor network QoS and the mobile users QoS, with this QoS decision maker makes the decision to which network the mobile user has to direct the connection [6]. Nowadays vertical handoff decisions are made based on other factors such as bandwidth, QoS, type of network, cost function along with the RSS. The scope of this thesis is to develop a fuzzy rule based vertical handover decision algorithm. Fuzzy rule based VHO decision algorithm is compared with the conventional RSS based vertical handover algorithm and technique for order preferences by similarity to an ideal solution (TOPSIS) multicriteria vertical decision algorithm for random and geographically restricted mobility model.

1.1 Objectives

The objectives of this thesis are given below:

- To develop a vertical handover decision algorithm based on a set of input parameters using fuzzy rule based scheme.
- To compare the developed fuzzy rule based handover decision algorithm with TOPSIS method of handover decision algorithm and RSS based decision algorithm in terms of number of handover, load balance index and blocking probability for random waypoint and Manhattan mobility models.

2 Related Theory

2.1 Wireless Network

A wireless network is a network that uses radio waves to connect homes, businesses and other wirelessly enabled devices to the Internet whereas a wired network uses a dedicated cable to provide the same services. A wireless network typically consists of one or more access points, example of which may be a router, through which users are connected to the Internet. The area of coverage, QoS, data rate and the type of services an access point can provide depends on the standard of the wireless network. The three wireless networks used for the simulation of heterogeneous network overlay are WiMAX, WCDMA and WiFi.

2.1.1 WiMAX

WiMAX, which stands for Worldwide Interoperability for Microwave Access, is a WMAN as described by the IEEE 802.16 standards for broadband wireless access. The purpose of WiMAX is to promote deployment of broadband wireless access networks by using a global standard and certifying interoperability of products and technologies. WiMax is intended to work outdoors over long distances of 50km radius, covering much longer distance than WiFi. It supports non line of sight communication (NLOS), uses adaptive antenna system (AAS) and multiple-input and multiple-output (MIMO) antenna system to increase efficiency in terms of coverage, power consumption and bandwidth usage.

2.1.2 WCDMA

Wideband Code Division Multiple Access (WCDMA) is a part of IMT-2000 (International Mobile Telecommunications) or universal mobile telecommunications service (UMTS) family of 3G standard. It uses spreading codes to separate cells and users as all the cells operate at same carrier frequency. It uses the same core network as that of 2G GSM supporting compatibility and mobility with GSM. This allows the coexistence of 2G and 3G sites and enables the use of WCDMA along with GSM in dual mode mobile operation to provide both 3G and 2G capabilities within the same network area.

2.1.3 WiFi

WiFi is a wireless LAN technology based on the IEEE 802.11 standard. As the requirement of users has changed with time, the version of 802.11 protocols has changed over the years, with the variation being 802.11a, 802.11b, 802.11g, 802.11ac and 802.11n. WiFi operates in the Industrial, Scientific and Medical (ISM) radio bands of frequency 2.4, 3.6, 5 and 60 GHz. 2.4 GHz is used frequently for household and business purposes. A WiFi access point has coverage of about 20m in radius for indoor applications. A larger coverage that can run many kilometers in radius can be achieved using multiple overlapping access points. It is also noteworthy that other devices that use ISM band like microwave ovens, Bluetooth devices, Zigbee devices, cordless phones and amateur radio can cause interference on the WiFi signal.

2.2 Propagation Model

A radio propagation model is the characterization of radio wave propagation as a function of frequency, distance and other conditions. As the path loss encountered along any radio link serves as the main factor for characterization of propagation for the link, radio propagation models typically focus on realization of the path loss.

Each individual telecommunication link has to encounter different terrain, path, obstructions and atmospheric conditions, it is necessary to formulate the exact loss for all telecommunication systems in a single mathematical equation. As a result, different models exist for different types of radio links under different conditions.

In the simplest form, the path loss can be calculated using the formula $L = 10\gamma \log_{10}(d) + C$, where L is the path loss in decibels, γ is the path loss exponent, d is the distance between the transmitter and the receiver, usually measured in meters, and C is a constant which accounts for system losses. The value of γ normally in the range of 2 to 4 (where 2 is for propagation in free space, 4 is for lossy environments and for the case of full specular reflection from the earth surface).

The cost 231 Walfish-Ikegami model is a J. Walfisch and F. Ikegami models and considers building in the vertical plane between transmitter and receiver. The accuracy of this empirical model is quite high because in urban environments the propagation in the vertical plane and over the rooftops (multiple diffractions) is dominating, especially if the transmitters are mounted above roof top levels [7]. The propagation between transmitter and receiver using Walfish-Ikegami model is shown in figure 2-1.

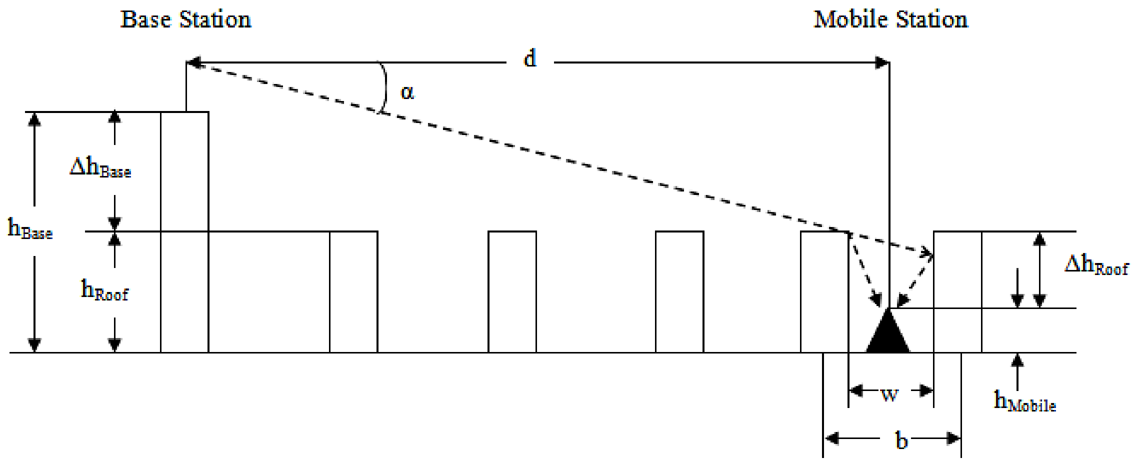


Figure 2-1Geometry of Cost 231 Walfisch- Ikegami model

In wireless environments, link budget (measured in dB) and spectral efficiency are the two primary parameters used for evaluating system performance. A link equation is given as

Perceived Power = Power of the transmitter + Gain of the transmitting antenna + Gain of the Receiving antenna – Sum of all losses..........................(1)

Equation (1) is used to find the absolute power perceived at the receiver after the signal has travelled through lossy medium and the input circuit. Link budget analysis takes into account factors such as path loss, receiver sensitivity, noise, enforcement and losses from the antennas and cables.

2.3 Mobility Model

A mobility model is used in a simulation environment to reflect the movement of a moving object with some speed. User mobility in handover simulation affects the performance of the wireless network as the user density, user coverage in the region of interest and user's speed has a direct relation on when and where a handover decision is to be taken and traffic load offered to each access point. A good users' mobility model is of great importance in high fidelity simulations of wireless system.

Many studies and researches have been performed on various mobility models. The most commonly used approach in wireless systems is random mobility model, the types of which are random waypoint model, random walk model and random direction model. In random-based mobility models, the mobile nodes move randomly and freely without restrictions. To be more specific, the destination, speed and direction are all chosen randomly and independently of other nodes [8]. Random waypoint model has been used to emulate the random movement of mobile station in this study with a pause time of zero. In random waypoint mobility model, the velocity and the direction of the user is chosen randomly and independently of other mobile station. After each time interval, at the destination the user pauses for a certain 'pause time' and again the velocity and direction of the user is chosen randomly for the next time interval. For the case when 'pause time' is 0, the mobility is continuous.

A class of geographically restricted model is another commonly used mobility model where the user's movement is restricted by the streets, pathways and obstacles. Two such models that are quite relevant in depicting the user movement in the urban street grid is City section model and Manhattan model. These two mobility model bounds the mobile node to move in the horizontal and vertical streets as provided in the topology. Manhattan model is a probabilistic method in the sense that selecting a new direction at the intersection of horizontal and vertical streets is based on probability. In the city section model each mobile node selects a destination and to reach the destination from the source a maximum of one horizontal and one vertical path can be chosen. A slight variation of Manhattan model is used in this research to represent the user mobility in the planned urban area.

Random mobility models are repeatedly used in simulation environment due to its simplicity and ease of use but it largely fails to reflect the movement of user in a practical scenario as user node does not move in random path haphazardly. Their mobility is constantly restricted by factors such as obstacles, roads and streets. In this context, geographically restricted mobility models like Manhattan model gives a good picture of the actual mobility scenario.

2.4 RSS Method

In telecommunications, RSSI is a measurement of the power present in a received radio signal. RSS can vary greatly with distance, frequency of use and the environment the wireless device is present and impact functionality in wireless networking. In the past, handoff decisions have been based on an evaluation of the RSS between the base station and the mobile node [5]. Handover is carried out only on the basis of received signal strength from different access networks as shown in figure 2-2.

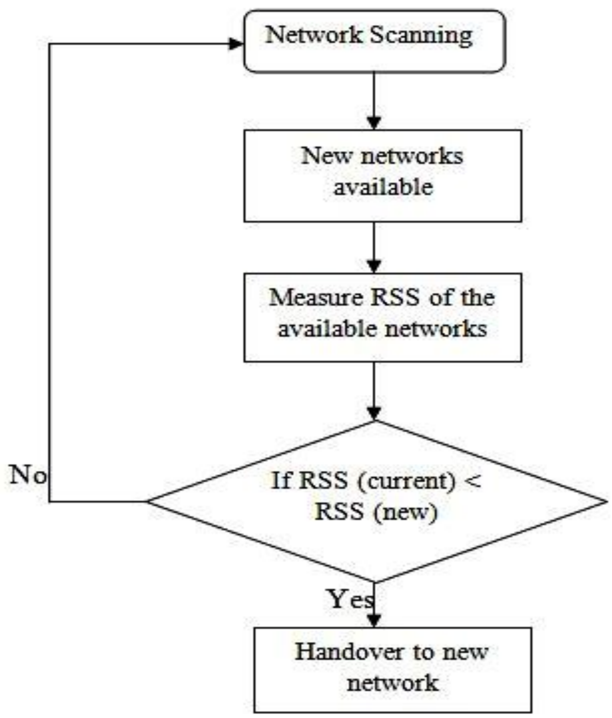


Figure 2-2 RSS based vertical handover mechanism

In RSS method for handover decision, wireless enabled mobile station continuously scans the networks around it. When it finds RSSI from new network it compares the RSS from its current associated network to the newly found networks. It then initiates handover if the signal strength from new network is found to be greater than current RSS. RSS method is efficient for horizontal handover which constitutes handover in the same network but for vertical handover it causes inefficient handoff and unbalanced network load. It is considered the easiest and conventionally used method for handover by many mobile service providers even today. The general mechanism of RSS based handover is given in figure 2-2.

2.5 TOPSIS

TOPSIS Multicriteria Decision, the technique for order preferences by similarity to an ideal solution (TOPSIS) requires subjective weightage value to each criterion to calculate the decision. It is widely used MADM (multiple attribute decision making) algorithm developed by Yoon and Hwang [1].

2.6 Fuzzy Logic

Fuzzy logic is a system of multi-valued logic. The theory of fuzzy sets relates to classes of objects with unsharp boundaries (unlike sharp boundary of ‘0’ and ‘1’) in which membership is a matter of degree [9]. Fuzzy Logic Control (FLC) is a non-linear control method, which attempts to apply the expert knowledge of an experienced user to the design of a controller. The fuzzy control system contains four main parts, the fuzzifier, the fuzzy rules base, the fuzzy inference engine, and the defuzzifier. The fuzzifier maps the real valued numbers into a fuzzy set, which is the input to the fuzzy inference engine. The fuzzification process includes the definition of the universe of discourse and the specification of the linguistic variables, the fuzzy sets for the linguistic variables, and the membership functions for the specified fuzzy sets. The fuzzy rule base consists of a collection of fuzzy IF-THEN rules to represent the human knowledge about the problem. The fuzzy inference engine maps the input fuzzy sets into output fuzzy sets and handles the way in which the rules are combined just as humans use many different types of inferential procedures. The defuzzifier task is the reverse operation to the fuzzifier. It maps the output fuzzy sets into real valued numbers [1]. The fuzzy inference system for handoff mechanism is shown in figure 2-3.

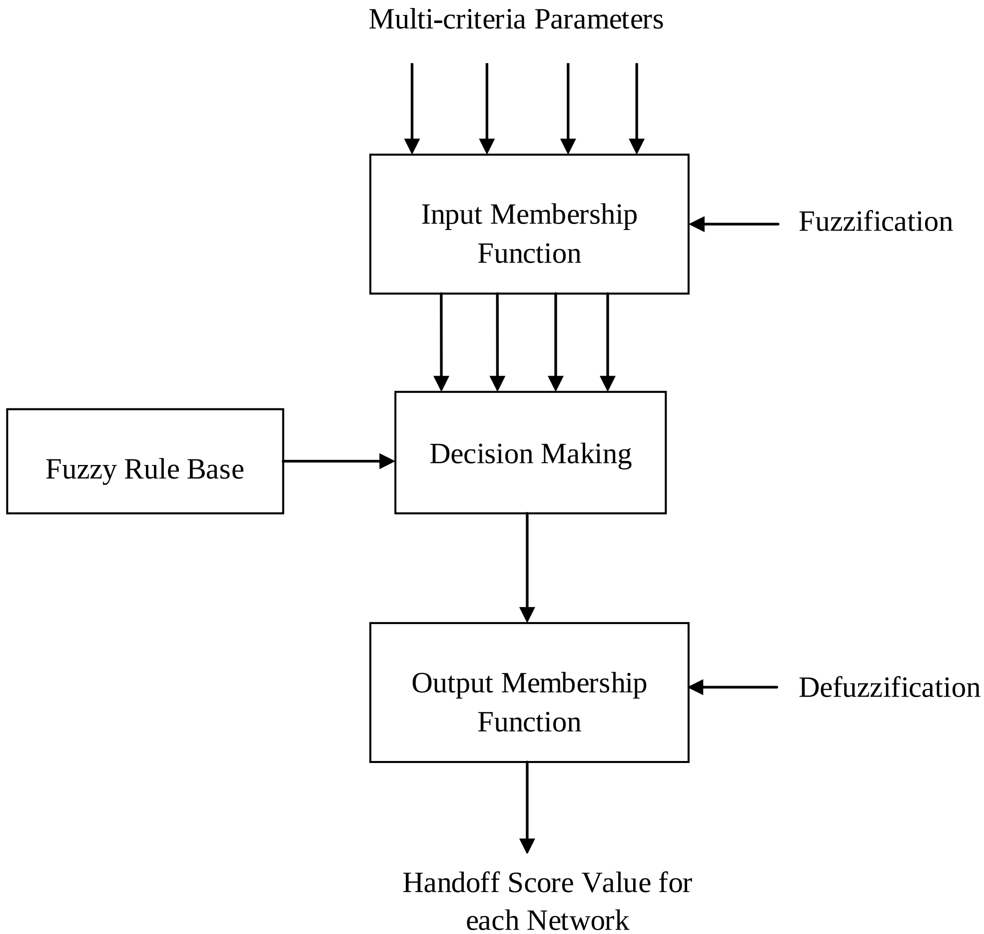


Figure 2-3 Fuzzy rule based handoff mechanism system

2.7 ID3 Method

In decision tree learning, Iterative Dichotomizer 3 (ID3) is an algorithm developed by Ross Quinlan. It is a top-down greedy heuristic method that is used to generate a decision tree from a data set, S. ID3 algorithm iterates through every unused attribute of the set S and calculates the entropy H(S) (or information gain IG(A)) of that attribute and selects the attribute which has the smallest entropy (or largest information gain) value [10]. The set S is then split by the selected attribute to produce subsets of the data. The algorithm continues to recur on each subset, considering only attributes never selected before. ID3 attempts to make the shortest decision tree out of a set of learning data but shortest may not always be the best classification and it also requires learning data to have completely consistent patterns with no uncertainty to give a more effective decision tree.

Algorithm for ID3 method

1. Find the entropy of every attribute using the data set S
2. Split the set S into subsets using the attribute for which entropy is minimum
3. Make a decision tree node containing that attribute
4. Repeat the process on subsets using remaining attributes

The use of ID3 algorithm in this research is to reduce the number of rules in the fuzzy system and make the decision tree more compact.

3 Literature Review

The network scenario for this dissertation has been developed using some of the concept of integrated network scenario of [3, 11]. These researches have proposed an improved TOPSIS method which is an MADM method of network analysis for handover decision. Different priorities criteria (i.e. taking different set of weights to the input parameters) are considered separately to deal with different demand requirement of users.

Random mobility models are mostly used for the simulation of user mobility in mobile ad-hoc network scenario. The simulation of large scale wireless networks, the considerations to be made and the factors that affect the performance of wireless networks and the study of user mobility, network topology construction and management, synchronization among the networks are discussed in [12]. A survey of various random mobility models in wireless ad-hod networks like random waypoint model, random walk model, non-uniform spatial distribution and random direction model are studied in [8, 13]. They have also gone a little further in studying about various group mobility models. Random waypoint mobility model developed by D. B. Johnson and D. A. Maltz [14] is widely used to emulate the movement of mobile hosts in an ad-hoc network. Due to an unrealistic mobility pattern with sharp turns at each interval, other realistic mobility models have been studied in recent researches over random waypoint mobility. City section and Manhattan models, studied in [13], where the mobile hosts are bound to move along fixed pathways are very common in simulation environment to mirror the mobility in urban city areas. The concept from these papers has been a basis to understand the random waypoint mobility model and Manhattan mobility model, whose slight variation is used in this research.

Various different approaches to horizontal and vertical handover have been discussed in [15]. A generalized approach to RSS based handover is also considered worthy of discussion in vertical handover approaches. Current handover methodologies like RSS based scheme, QoS based scheme, decision function based scheme, network intelligence based scheme, and context based scheme have been discussed.

A vertical handover strategy in providing better QoS in WiMAX/WLAN interworking system has been proposed in [2]. The performance of the system is analyzed with respect to system throughput and number of users blocked. A hybrid approach of combining TOPSIS and Fuzzy Logic in parallel to deal with VHO issues by applying TOPSIS weightage approach to all the input parameter and parallely developing a subsystem for each parameter using fuzzy logic is performed in [1].

Fuzzy rule based QoS aware VHO mechanism has been proposed in [16] considering a heterogeneous network consisting of one UMTS network, one GPRS network and a WLAN network. The evaluation for this system is performed considering 7 states in heterogeneous network using non birth-death Markov chain. The states correspond to the available networks considered in the simulation. A vertical handover approach for providing the users' requested services by different networks to satisfy the users demand is developed in [5]. With a goal of maximizing the quality of service experienced by user, the concept of completing user requested services by different networks that can best address the request using cost function for VHO decision phase is proposed in this paper.

TOPSIS MADM process is used to select the best network among a multiple wireless networks in [6] and some discussion on fuzzy TOPSIS method is done in [17]. Four vertical handoff decision algorithms, namely, Multiplicative Exponent Weighting, Simple Additive Weighting, TOPSIS and Grey Relational Analysis have been compared in terms of bandwidth and delay in [18].

The fuzzy logic toolbox user's guide, [9] proves to be very effective in learning and understanding the fuzzy inference system (FIS) system toolbox in MATLAB. It provides a detailed guide to developing and using FIS system. A way to produce meaningful and simple fuzzy rules and using ID3 method to dealing with many inputs variables has been performed in [19]. Further it uses this method to produce a decision tree that can be used to predict the marks obtained by students based on old marks. The concept of reducing the number of rules used in FIS and using the reduced set of rules in predicting the output for a set of input conditions has been very helpful in reducing the number of fuzzy rules for this dissertation.

4 Methodology

4.1 Model Development

The model for the network overlay has been created in MATLAB. The overlay region is a 10x10 km^2 region consisting of one WIMAX AP, four WCDMA node-Bs and eight WLAN APs with an omni-directional antenna placed at the center of each cell. The base station parameters used for these APs are given in table 4-1. The placement of AP in the overlay is shown in figure 4-1. The square, triangular and circular symbols at the centre of the circle represent the AP, and the circle around it represents the radius within which each AP has an influence.

Table 4-1 Base Station Parameters

Properties	WLAN	WCDMA	WiMAX
Cell Radius (m)	700	2300	5000
EIRP (dBm)	20	18	60
Receiver Sensitivity (dBm)	-119	-100	-100
Cell Edge Receiving Level (dBm)	-119.58	-100.45	-100.12
Operating Frequency (MHz)	2450	2100	3500

The coverage by WiMAX AP is an area of 5 km radius and the coverage by each WCDMA node-B is of radius 2.3 km. Each WLAN's radius of influence is 0.7 km. The effective isotropic radiated power for WLAN, WCDMA and WiMAX is taken to be 20, 18 and 60 dBm respectively. The cell edge receiving level for these access network has been calculated for the furthest point i.e the circumference of each AN's radius of influence using the respective propagation model as given in equation (4), (5) and (6). This value is the tentative receiver sensitivity which is also used as the threshold RSSI value that indicates when the vertical handover decision algorithm should be triggered. The value for cell edge receiving level/threshold for WLAN, WCDMA and WiMAX are found to be -119.58, -100.45 and -100.12 dBm respectively.

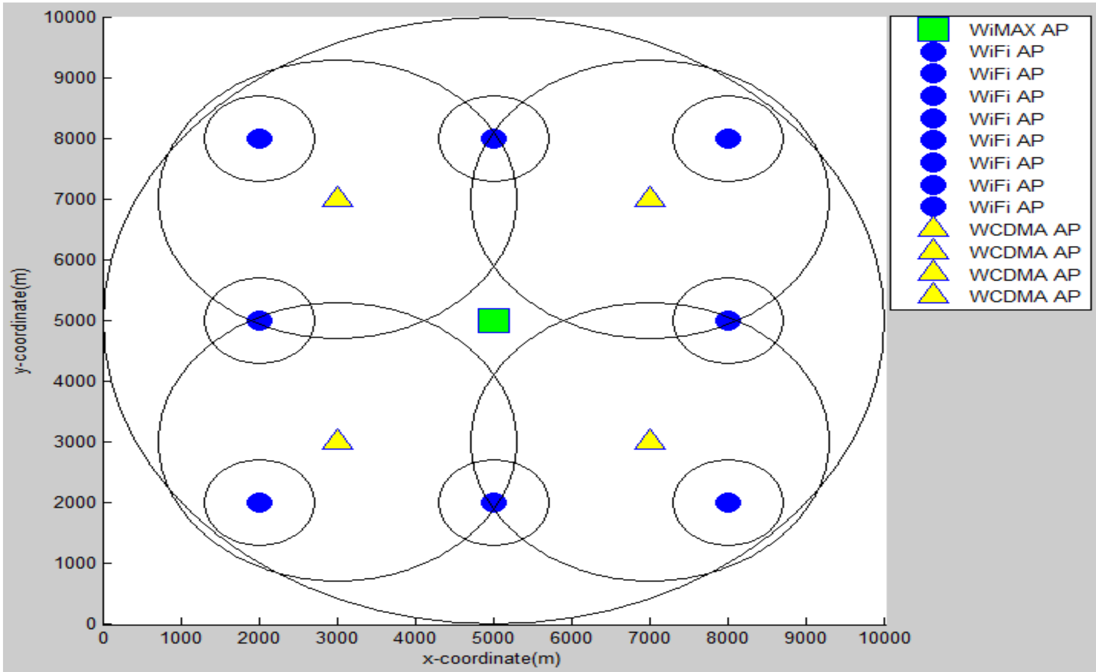


Figure 4-1 Heterogeneous Network Topology

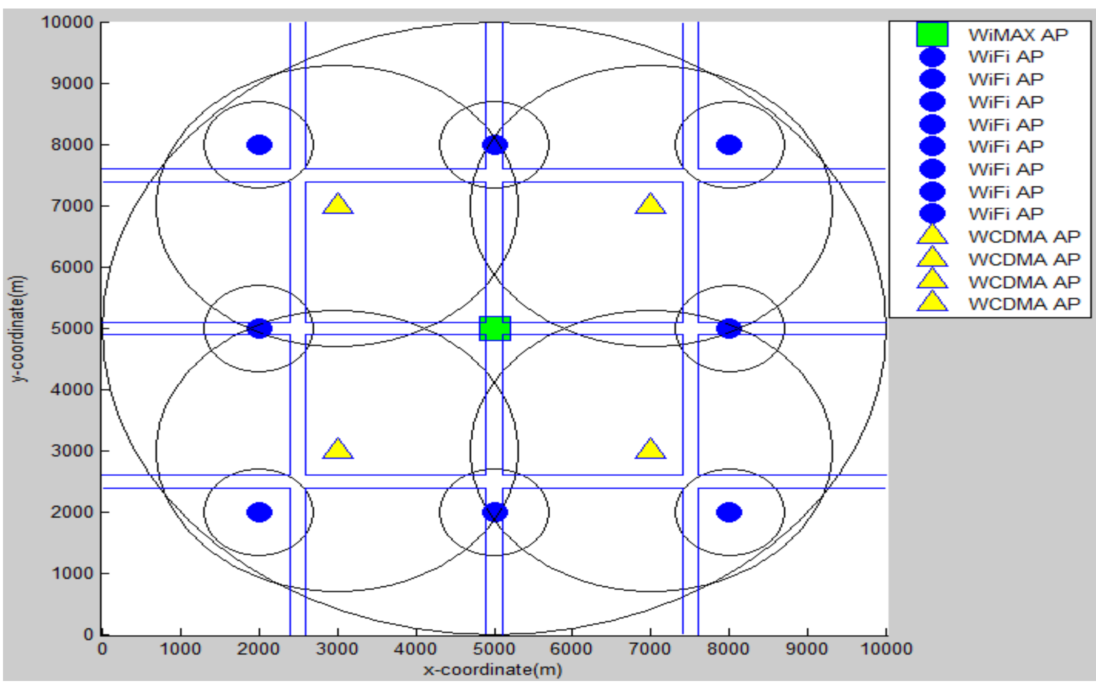


Figure 4-2 Network topology with vertical and horizontal city street grid

The network topology used for both random waypoint mobility and Manhattan mobility is shown in figure 4-1. Apart from this for the case of Manhattan mobility model a fixed horizontal and vertical street grid is placed in the overlay as shown in figure 4-2. The width of the road is taken to be 50 m wide. The road sections are either 2475 or 2450 meter in length. The intersection of vertical and horizontal streets is an area of 50x50 m^2.

4.2 Mobility Models

The two mobility model taken for the study are random waypoint mobility model and a variation of Manhattan mobility model.

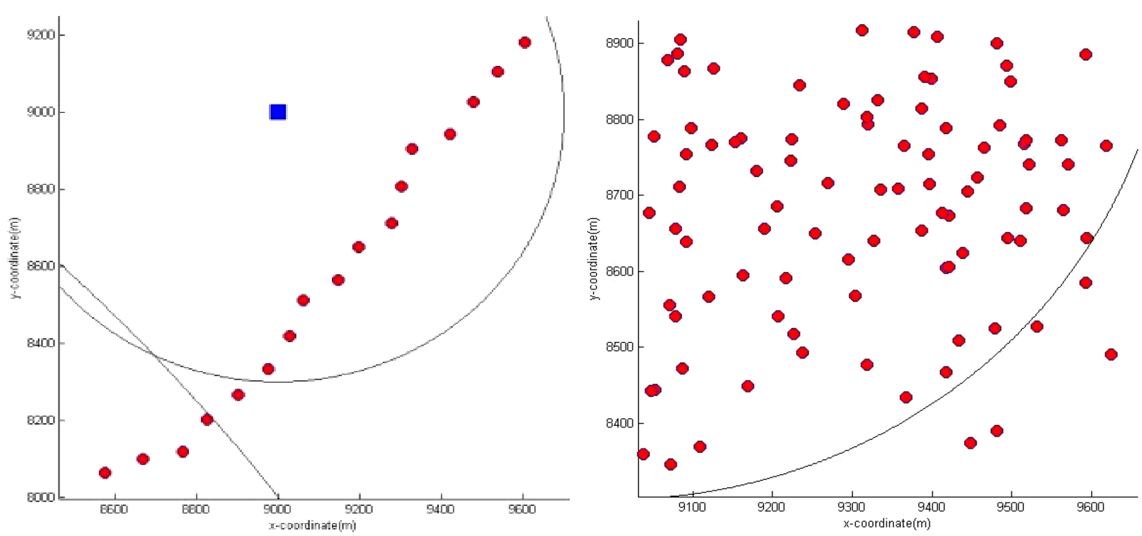
4.2.1 Random Waypoint Mobility Model

A random mobility model, named random waypoint model, has been used in order to simulate the users' movement with respect to time. The pause time for the simulation is taken to be zero. The simulation has been performed for 1000 seconds with a sampling time of 5 seconds. For a user speed of *v* and an initial location of (x, y), its next location (x_{next}, y_{next}) is determined by generating a random value of angle, θ.

$$x_{next} = x + v*t*cos\theta \quad \ldots(2)$$

$$y_{next} = y + v*t*sin\theta \quad \ldots(3)$$

where t represents a sampling time of 5 sec.



(a) (b)

Figure 4-3 Random waypoint mobility (a) Single user (b) Multiple user

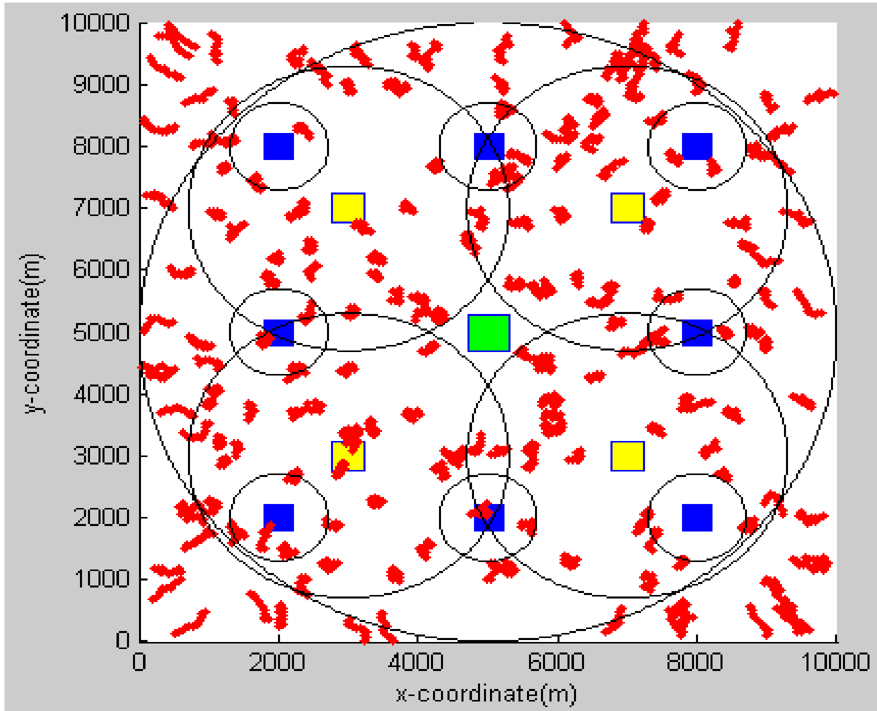


Figure 4-4 Multiple users distributed over the heterogeneous network using random waypoint mobility model

A discrete set of location a user traverses at an interval of 5 sec can be found using equation (2) and (3). The traversal of a user is tracked at an interval of 5 sec as shown in figure 4-3(a), where the movement is determined by equation (2) and (3). The location traced by multiple users at an interval of 5 sec is plotted in figure 4-3(b). Two hundred users randomly distributed in the overlay just at the beginning of their mobility are shown in figure 4-4. The entire users are considered to be active throughout the simulation time. In these figures, random dots represent the path followed by user and the square dots represent the AP and the circular lines represent the influence region of each AP.

4.2.2 Manhattan Mobility Model

A variation of Manhattan mobility model has been simulated to mimic the mobility of users in urban planned street pathways. The mobile hosts are restricted to move only in the planned roads/streets while pursuing their movement in the network region. A mobile user starts its movement randomly from any part of the streets except the intersection of vertical and horizontal streets. If a mobile user starts it movement from the lower half vertical streets its forward direction is upward while if a mobile user begins its movement from the above half vertical streets, its forward direction is downward. Similarly if a user begins its movement from left half horizontal streets its forward direction is left and if originates from right half horizontal streets then its forward direction is left. A mobile user once begins its movement moves in its forward direction until it reaches an intersection where it gets to choose among straight, left or right direction. This choice at the intersection is taken probabilistically with equal chances for three directions. Once the choice is made the node moves in the chosen direction until it reaches another intersection where again the node has a choice to make. If a user goes beyond the boundary of 10*10 km^2, the user is wrapped around the simulation area at the opposite boundary where the user can continue their mobility. This ensures the number of users in the simulation area to be constant.

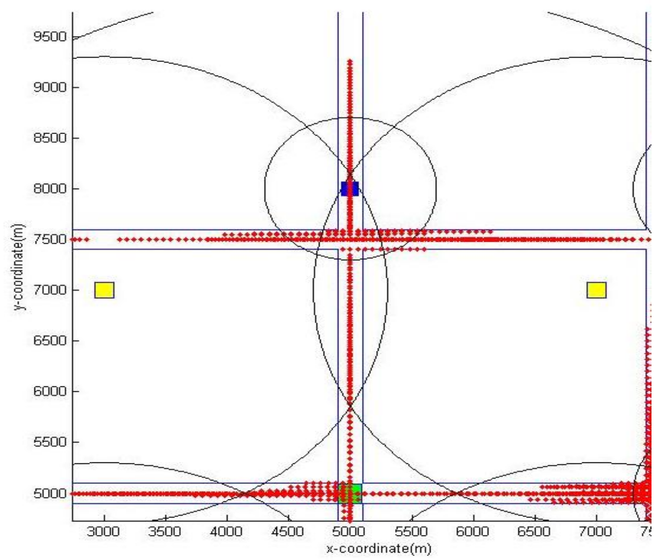


Figure 4-5 Manhattan Mobility for multiple users

The simulation for Manhattan mobility is also performed for 1000 seconds and the user position is tracked at each 5 seconds interval. The mobility pattern for Manhattan mobility is shown in figure 4-5. The total number of mobile users is taken to be 200. The vertical and horizontal lines make the streets and circular lines represent the influence of APs. The dotted lines within the streets represent the path traced by the mobile users.

4.3 Propagation Model

The empirical loss model is selected for WiMAX and WLAN whereas COST 231 Walfish-Ikegami model is selected to account for the free space propagation loss of WCDMA.

$$L(d) = L_0 + 10*\gamma*\log(d/d_0) \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$L(d) = L_0 + 10*\gamma*\log(d) \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$L(d) = 42.6 + 26\log(d) + 20\log(f) \ldots\ldots\ldots\ldots\ldots (6)$$

Equation (4) represents empirical WiMAX model where L_0 is 105.45dB measured at d_0 = 200m and γ = 3.911. Equation (5) represents empirical WLAN model whereL_0 is 40 dB referenced at 1m and γ = 3.5. Similarly equation (6) represents COST 231 Walfish-Ikegami model for WCDMA where *d* is distance from base station to mobile user in kilometers (km) and *f* is operating frequency in MHz. These path loss models along with the effective isotropic radiated power (EIRP) are used to calculate the RSS at a distance *d*. Finally the perceived power at the receiver is calculated using equation (1).

4.4 RSS Handover Decision Algorithm

This algorithm considers only the RSSI from various access networks to decide when the handover should be carried out or not. When the received signal strength from current AN is less than the receiver sensitivity (i.e. threshold value), a user at a location scans the received signal strength from the nodes within whose radius of influence it is located. On finding the largest RSSI from a node, it initiates handover to that node.

Algorithm for RSS Handover Decision

1. Find if the RSS from current network is less than the receiver sensitivity of the user
    a. If Yes,
        i. Measure RSS from each available AP to the user
        ii. Handover to a network that provides the maximum RSS
    b. If No, stay in the current network
2. Repeat steps 1 after a fixed interval.

4.5 TOPSIS Multicriteria Handover Decision Algorithm

The four input criteria used for TOPSIS analysis are the RSS, mobile speed, traffic class and network occupancy. RSS indicates the signal strength received by the user from an AP. The mobile speed is the speed with which a user is moving in the overlay. Traffic class indicates the type of service a user is requesting from a wireless access network. Network occupancy is the measure of how much occupied a network is or it indicates the availability of network resources to provide service to a user. The value of these parameters is dependent on distance and/or time. The RSSI, mobile speed and traffic class are mobile station parameters while network occupancy is base station parameter. Table 4-2 represents the range of values of parameters taken for TOPSIS analysis.

Algorithm for TOPSIS Handover Decision

1. Find if the RSS from current network is less than the receiver sensitivity of the user
   a. If Yes,
      i) Find the value of mobile station and base station parameters: RSS, user speed, traffic class user is requesting and the percentage of network occupancy
      ii) Calculate the weighted sum of these parameters for each available network
      iii) Handover to the network with the highest weighted sum
   b. If No, stay in the current network
2. Repeat step 1 after a fixed interval

4.6 Fuzzy Rule Based Handover Decision Algorithm

The RSS, mobile speed, traffic class and network occupancy are the four input criteria used for fuzzy inference system. The universe of discourse for each of the inputs is given in table 4-2. The membership functions for the input parameters are linguistically represented as Low, Medium, and High. Whenever a handoff is required the value of the input parameters at that instant are given as input to the fuzzy system. The output is a handoff score value drawn from the fuzzy rule base and ranges from 0 to 1. The centroid method is implemented for defuzzification. A high value of handoff score value indicates a potential network to which the user may be handed over.

The ID3 method begins with a set of examples and ends with a set of rules in the form of a decision tree which then can be applied to unknown cases. 81 rules can be made for each network (four input parameters and 3 membership functions) which is recursively split by the ID3 and creates a decision tree using Shannon Entropy formula. The total numbers of ID3 derived fuzzy rule are narrowed down to a total of 45. For the case with 3 membership function whose linguistic representation is low, medium and high, the entropy equation for each input parameter is given in equation (7).

$$H = -\sum_{i=1}^{n}\left[N_L log_3\left(\frac{N_L}{N_L+N_M+N_H}\right) + N_M\, log_3\left(\frac{N_M}{N_L+N_M+N_H}\right) + N_H log_3\left(\frac{N_H}{N_L+N_M+N_H}\right)\right] \ldots.(7)$$

Where N_L, N_M, N_H represents the total instances of the low, medium and high cases for each input parameter i.

Table 4-2 Universe of discourse for input parameters for TOPSIS and Fuzzy analysis

Parameters	WLAN	WCDMA	WiMAX
RSS (dBm)	(-120) – 90	(-120) – 40	(-120) – 50
Mobile Speed(m/s)	0 – 12	0 – 12	0 – 12
Traffic Class(kbps)	0 – 720	0 – 720	0 – 720
User Capacity	0 – 50	0 – 100	0 – 200

The variation in the mobile speed is taken based on the fact that pedestrian mobile station normal speed is around 1.3 m/s and that of medium speed vehicular mobile station varies between 4-6 m/s and very high speed vehicular mobile station may reach up-to 11m/s. The low value of traffic class represents service requests for lower bit rates applications while higher value represents service requests for higher bit rate applications.

Algorithm for Fuzzy Rule Based Handover Decision

1. Find if the RSS from current network is less than the receiver sensitivity of the user
    a. If Yes,
        i) Find the value of mobile station and base station parameters: RSS, user speed, traffic class user is requesting and the percentage of network occupancy
        ii) Find the handoff score value for each AP using fuzzy interference system

iii) Handover to the network with the highest handoff score

b. If No, stay on the current network

2. Repeat step 1 after a fixed interval

At the beginning of the mobility the mobile and base station parameters of each user is measured and passed to the FIS. This determines the initial associated AP for each user. As the active users traverse in the overlay the parameters is updated and when the user reaches the cell edge (i.e when the RSS from current AP reaches receiver sensitivity value or less), the mobile station requests for handover. Then the value of parameters is analyzed by the FIS and the best AN for the user to be handed over to is determined. This process of measuring the parameters values and determining whether or not handover should be executed is repeated after some time interval. The process of vertical handoff decision using fuzzy rule base system is shown in figure 4-6.

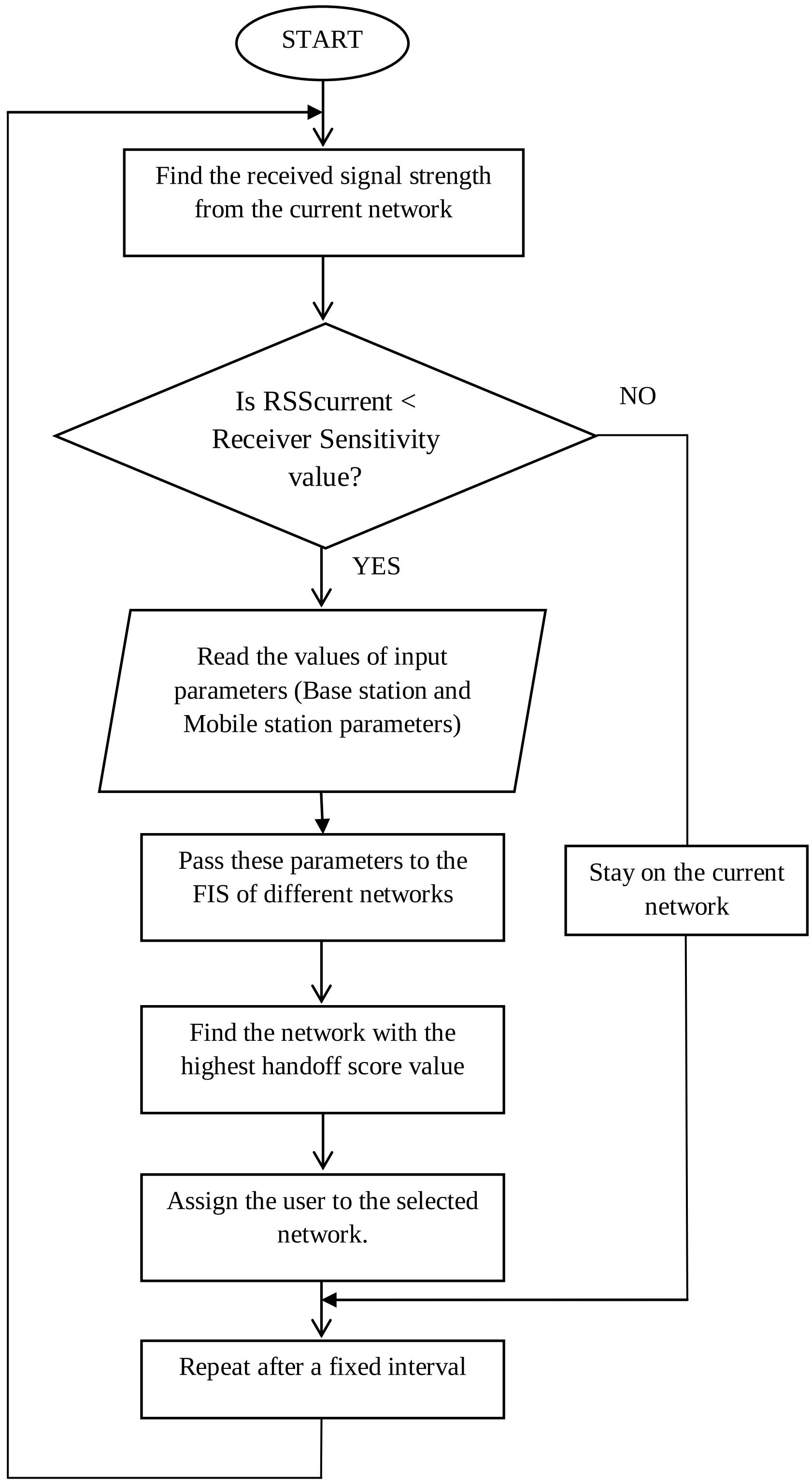
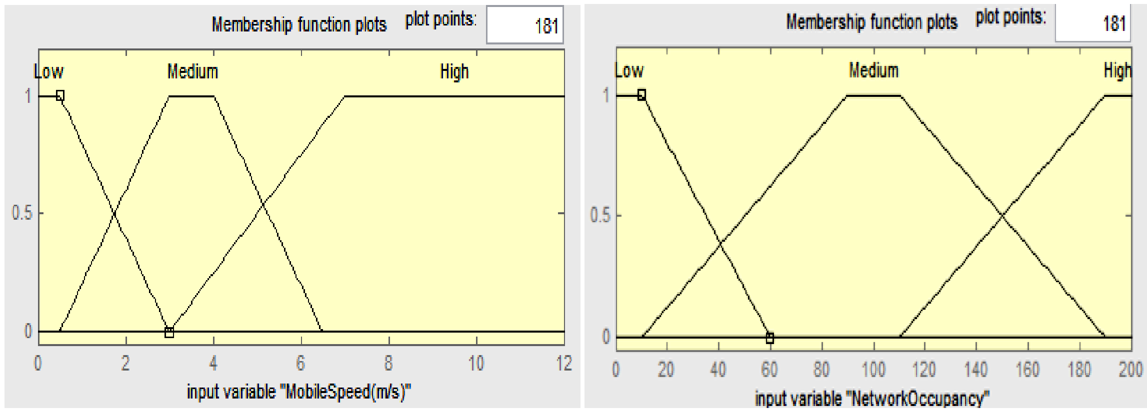


Figure 4-6 Multi-criteria Vertical Handover Decision Algorithm using Fuzzy Rule Based System



(a) (b)

Figure 4-7 Fuzzy membership function plots for input parameters (a) Mobile Speed (b) Network Occupancy

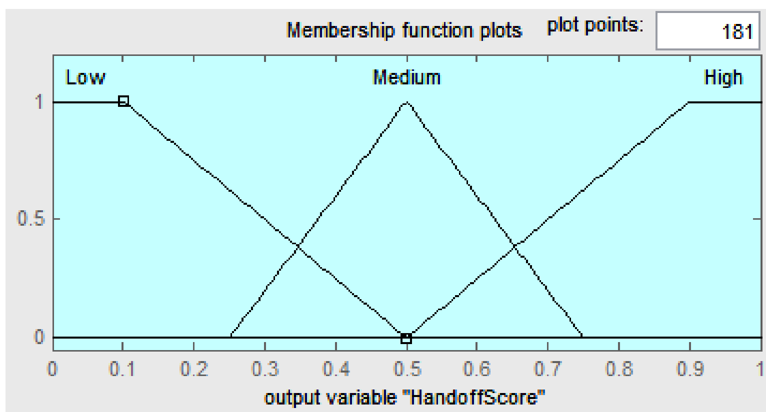
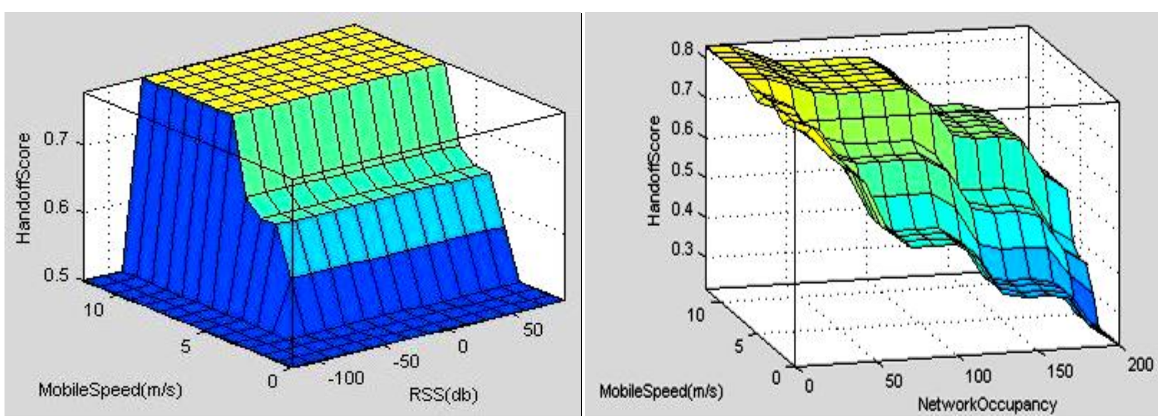


Figure 4-8 Output membership function plot



(a) (b)

Figure 4-9 Surface view plots of Handoff score with respect to (a) mobile speed and RSS (b) mobile speed and network occupancy

Fuzzy logic starts with the concept of a fuzzy set. A fuzzy set is a set without a crisp, clearly defined boundary. It can contain elements with only a partial degree of membership. A membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The input space is also referred to as the universe of discourse. Figure 4-7 (a) and (b) show the membership function of mobile speed and network occupancy. These parameters are defined by trapezoidal function and the universe of discourse for mobile speed is between 0 and 12 m/s. Similarly the universe of discourse for network occupancy is between 0 and 200 as seen in figure 4-7 (b). The output (handoff score value) membership function is shown in figure 4-8 which is defined along the universe of discourse of 0 to 1. The surface view plot for fuzzy rule based in figure 4-9 shows the dependency of the output on any one or two of the inputs i.e. it generates and plots an output surface map for the overall system. The dependency of the output handoff score value with mobile speed and RSS is shown in figure 4-9(a) and similarly, figure 4-9(b) shows the dependency of handoff score with input parameters mobile speed and network occupancy. Some of the fuzzy rule set for FIS is given in table 4-3.

Table 4-3 Some Rules for Fuzzy Inference System

S.N	RSS	Mobile Speed	Traffic Class	Network Occupancy	Handoff Score
1.	Low	Low	None	High	Low
2.	Medium	Medium	Medium	Low	Medium
3.	High	Medium	Low	High	Medium
4.	High	None	Medium	Medium	High
5.	High	High	Medium	High	High

5 Result and Discussion

5.1 Performance Measurement

The performance of the three VHO algorithms is measured on the basis of i) number of handoffs, ii) load balance index and iii) average blocking probability for two different mobility models. The total number of handoff during a time is an indication of a system performance as it is correlated with the signaling overhead. Very high value of number of handoff in a system may degrade the system's performance. Load balance index indicates how well the users are distributed in an environment containing multiple RATs.

$$D = (\Delta load_{WLAN-WCDMA} + \Delta load_{WLAN-WiMAX} + \Delta load_{WCDMA-WiMAX}) \times (3^{-1}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

$$B = 1 - Normalized\ (D) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

where, D = the difference in load densities between different RATs, B = balance index and

$$\Delta load_{WLAN-WCDMA} = |load_{WLAN} - load_{WCDMA}|$$

$$\Delta load_{WLAN-WiMAX} = |load_{WLAN} - load_{WiMAX}|$$

$$\Delta load_{WCDMA-WiMAX} = |load_{WCDMA} - load_{WiMAX}|$$

A low value of B (or high value of D) indicates an unbalanced system where some networks are overly congested while some are unused. A balanced system, system where the users are distributed well can serve more customers. Blocking probability is an indication of the number of handover requests that has been blocked by a system. The call arrival model in a system follows Poisson process with limited server number. Erlang B blocking probability model is taken to analyze blocking probability where lost calls are dropped or cleared. Blocking probability indicates the unavailability of circuit group to accept further calls. These performance metrics are used to evaluate the performance of three algorithms in a same network environment.

The network simulation is performed for 200 users for 1000 sec. The result has been taken by averaging the performance of 50 simulations. The sampling time has been taken to be 5 sec. At a single simulation, the speed and traffic class of 200 users are made constant and at each subsequent simulation speed and traffic class is varied.

5.1.1 Number of Handoff

The number of handoffs executed for the three algorithms using random waypoint mobility model as the time progresses is shown in figure 5-1. The number of handoffs executed for the three algorithms using Manhattan mobility model in figure 5-2. The number of handoff has been plotted cumulatively hence a value of handoff at a time indicates the total handoff executed till that instant of time.

It can be seen from the figures that the total number of handoff in the fuzzy system is the highest for both the mobility model. Using the random waypoint mobility model fuzzy system gives the total handover of 239 while handoff in the TOPSIS method is 98 and the value is 117 using RSS method. For the case of Manhattan mobility model, fuzzy method gives a total handover of 293, TOPSIS method gives a total handover of 193 and RSS method gives a total of 125 handovers throughout the simulation time.

The RSS method for handover decision tends to have less number of handover; this can be explained from the fact that in this method the mobile user solely determines the best signal strength AP and associates itself with that AP until the user moves out of the influence region of that AP. The other two methods has to consider four factors before deciding where to handoff this tend to give more frequent handovers than the RSS method.

It is noteworthy that the number of handoffs is higher in Manhattan mobility than random waypoint mobility for all three algorithms. The spatial characteristics of random waypoint mobility model is that even for a large simulation time the movement pattern of mobile host is restricted to a very small region around its starting point in the simulation area. As the users' position is not much changed even with the course of time, less number of handoff is required in random waypoint mobility model. Since in the Manhattan mobility a user has to move in the forward direction wherever it is in the street, the user's position is not restricted to a small region, hence higher number of handover occurs.

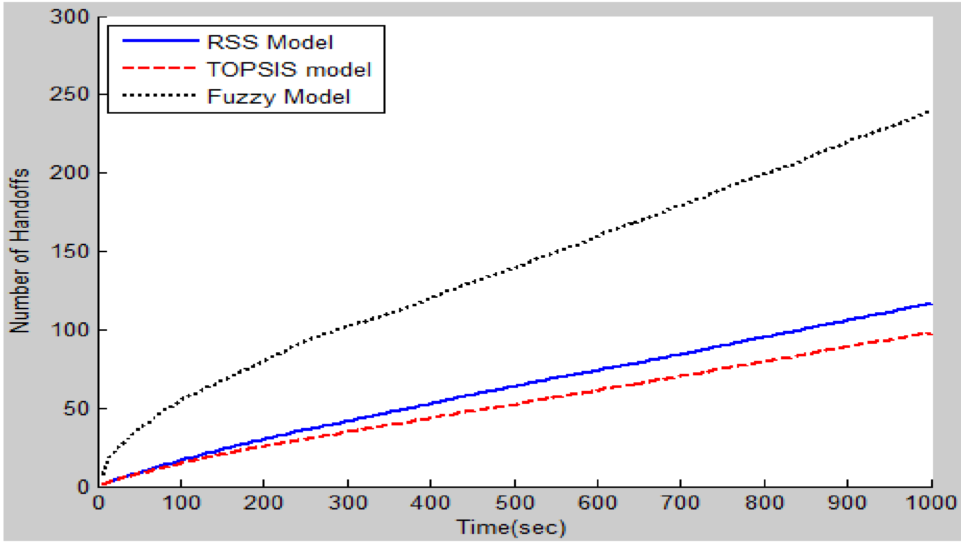


Figure 5-1 Cumulative number of handoffs with respect to time for Random Waypoint mobility

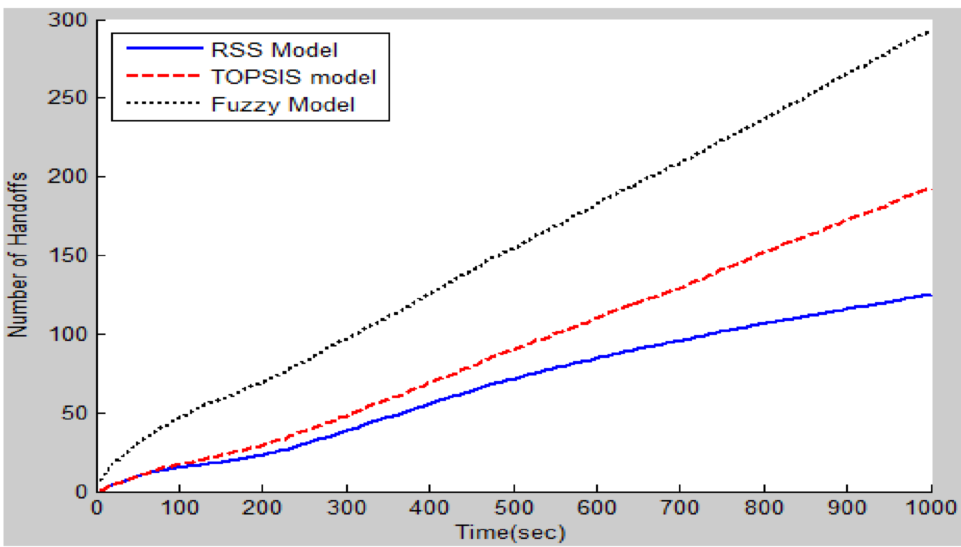
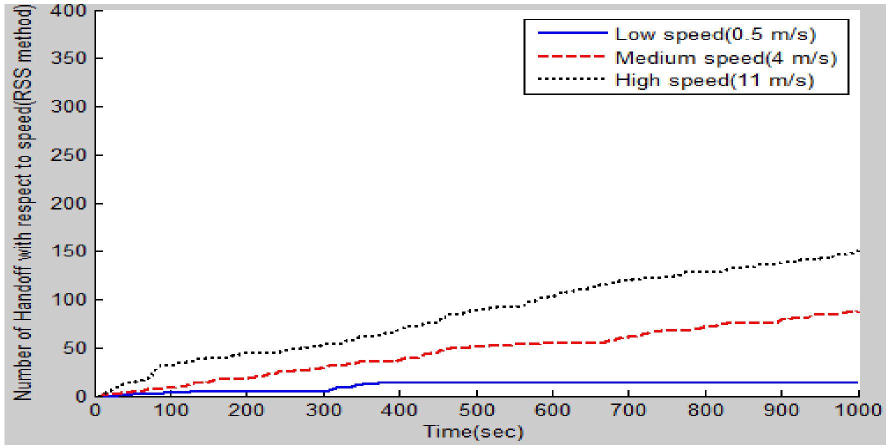
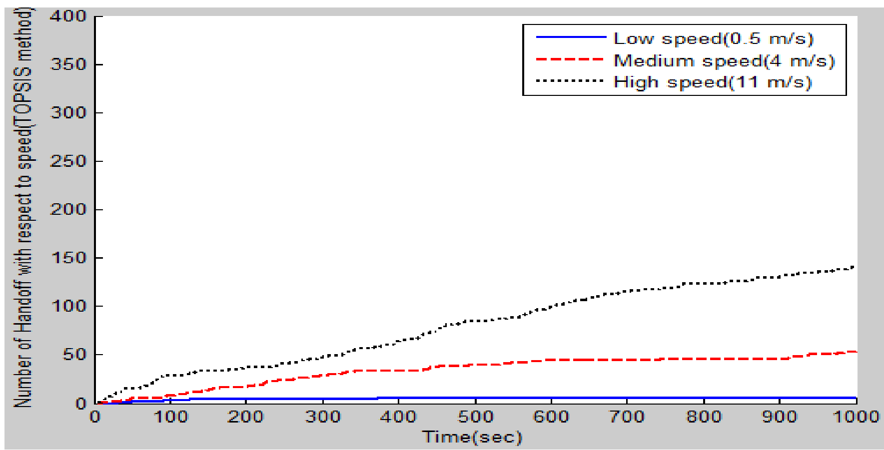


Figure 5-2 Cumulative number of handoffs with respect to time for Manhattan mobility model

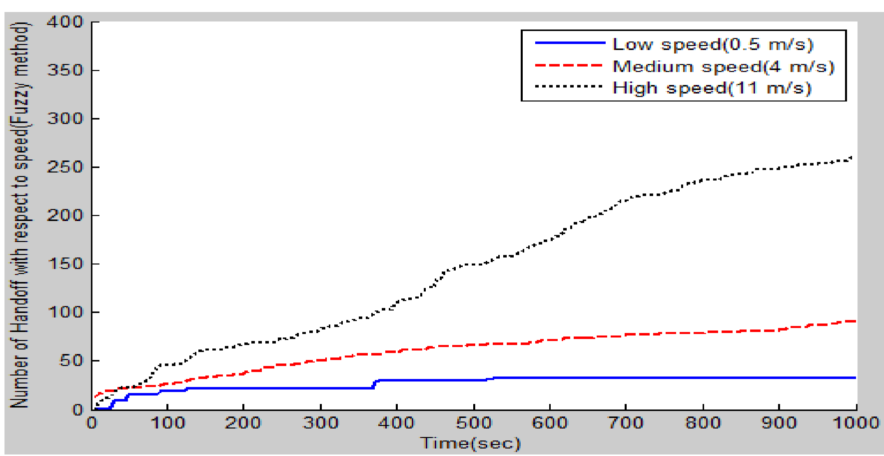
The number of handoff executions for different speeds of user for each algorithm separately for the random waypoint mobility model is shown in figure 5-3(a), 5-3(b) and 5-3(c). Similarly, figure 5-4(a), 5-4(b), and 5-4(c) plots the number of handoff executions for different speeds of user for three decision algorithms separately using Manhattan mobility model. The number of handoff for high speed user is the maximum and lowest for low speed user. High speed user tends to move in and out of the radius of influence of



(a)

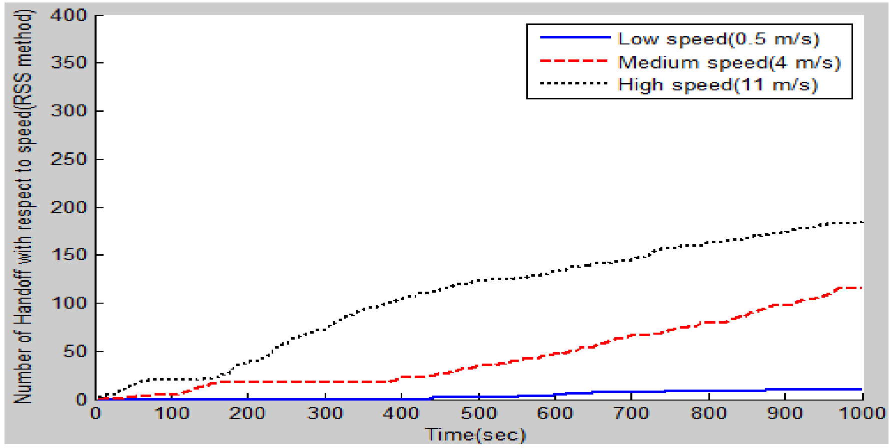


(b)

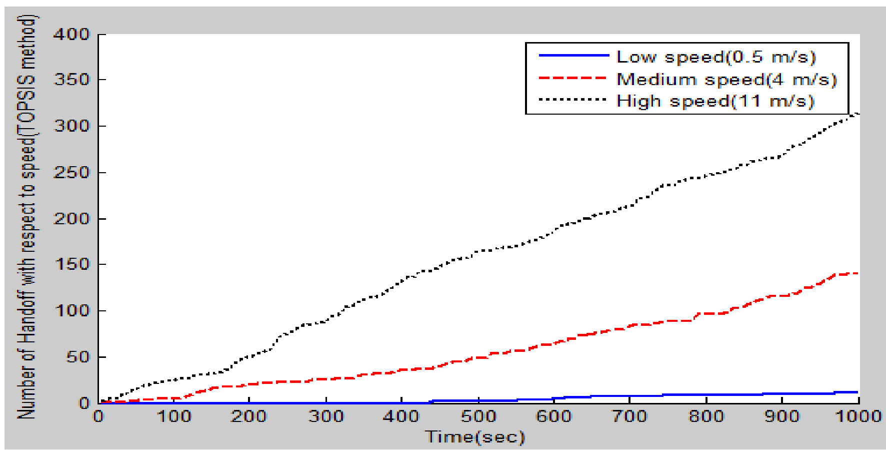


(c)

Figure 5-3 Number of handoff for low, medium and high speed user. (a) RSS method, (b) TOPSIS method (c) Fuzzy Rule Based method using random waypoint mobility



(a)



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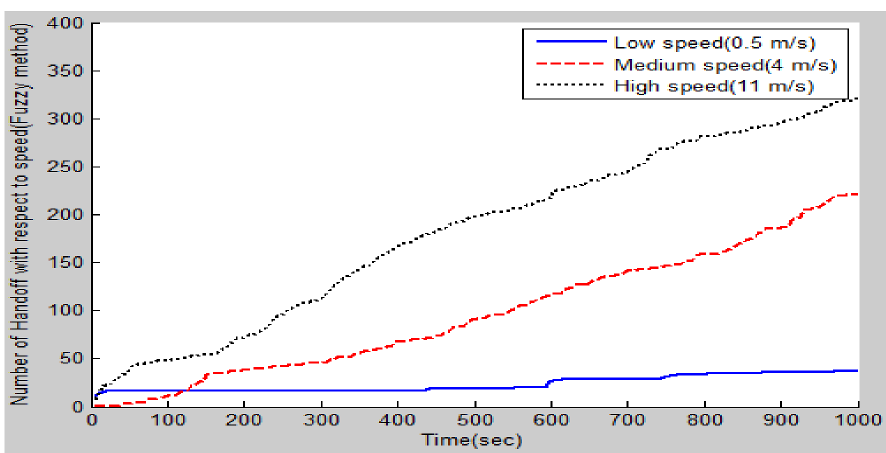


(c)

Figure 5-4 Number of handoff for low, medium and high speed user (a) RSS method, (b) TOPSIS method (c) Fuzzy Rule Based Method for Manhattan mobility an AP hence giving more handoff requests and hence more handoff execution. This can be seen from the curve for high speed user with speed 11 m/s. The less speed mobile users, as indicated by 0.5 m/s speed, take longer time to move out of the influence of an AP hence shows less number of handover. For a medium speed user, 4 m/s, the number of handover is in between that of low speed user and high speed user.

5.1.2 Load Balance Index

The comparison of the three algorithms on the basis of load balanced index for random waypoint mobility is shown in figure 5-5. The balanced index for fuzzy based algorithm is the best with an average value of 0.86 hence it utilizes more access nodes in a balanced way. The RSS based vertical handover system has a medium value of balanced index 0.61 and the TOPSIS method has the least value which is 0.45. Hence the Fuzzy algorithm balances load 25% better than RSS algorithm and 41% better than TOPSIS method. The load index value tends to be stable as the time progresses for each algorithm.

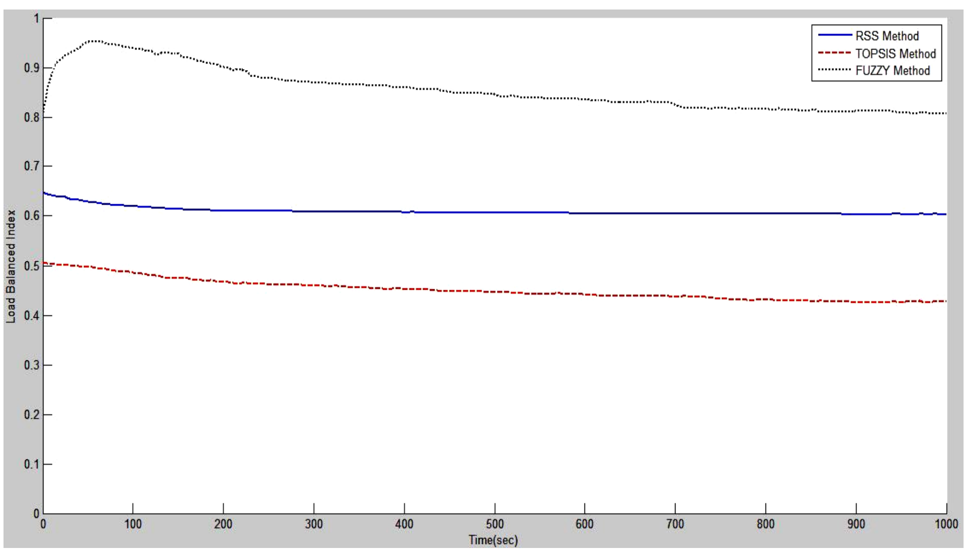
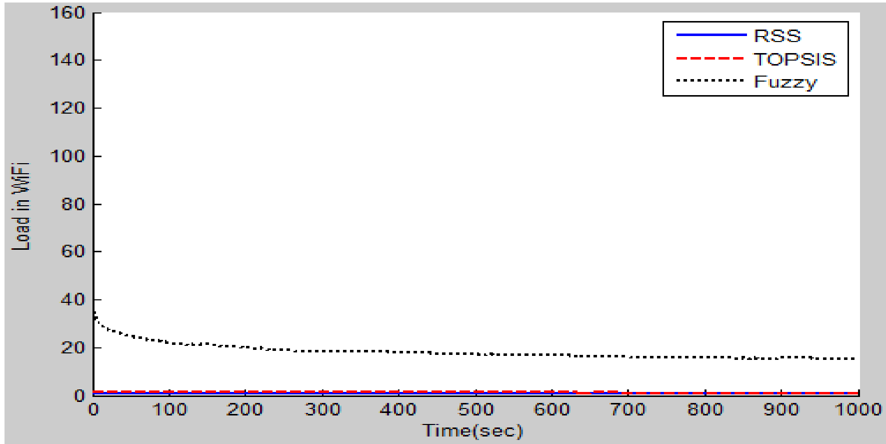
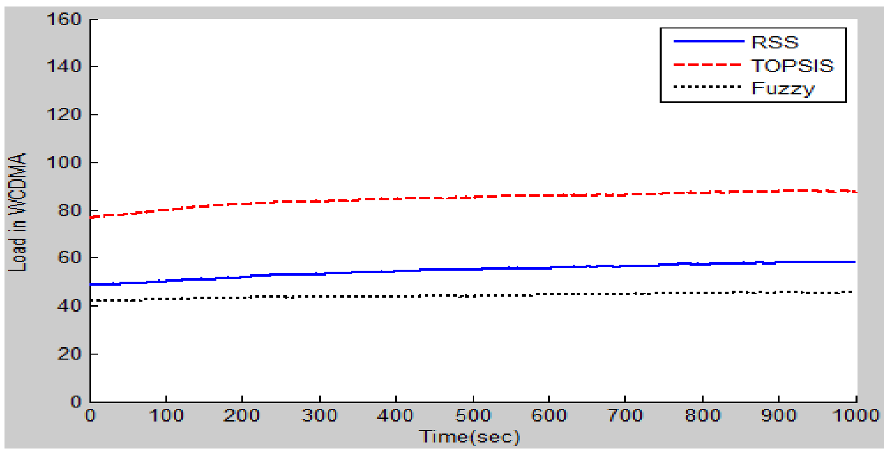


Figure 5-5 Balanced Index with respect to time for random waypoint mobility

The main benefit of fuzzy handover algorithm is that the interworking system has shared the traffic load more evenly among themselves rather than overloading some access networks as in the case of TOPSIS and RSS method. This fact is further supported in figure 5-6 (a), (b) and (c), where the load (number of users) in WiFi (WLAN), WCDMA



(a)



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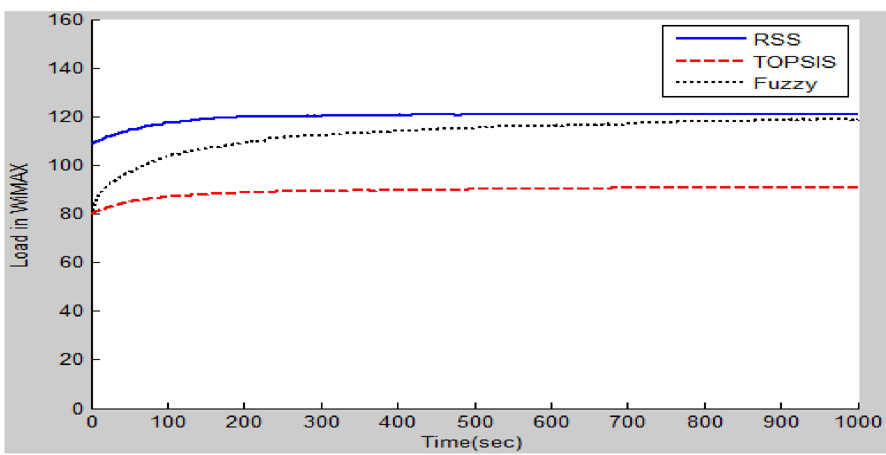


(c)

Figure 5-6 Number of user in (a) WiFi, (b) WCDMA (c) WiMAX network for random waypoint mobility and WiMAX has been shown respectively. The TOPSIS and RSS method of handover decision does not utilize WiFi network but load the WiMAX network the most. In the same scenario, fuzzy method utilizes all three networks to some extent hence has been able to distribute the load to all the existing networks. The load in the WiFi network has shifted to the WiMAX network at the initial phase of the simulation giving an initial fall in the load balance curve of the fuzzy rule based method. The region of influence of WLAN is small thus the tendency of users moving out of WLAN is higher than entering into it; hence the fall in load distribution of WiFi network is seen at the beginning of the simulation before the load remains almost constant.

The load balance index of different decision algorithms for the case of Manhattan mobility model is presented in figure 5-7. The load balanced index of the fuzzy method is the highest with an average value of 0.73, whereas the TOPSIS method has an average balanced index of 0.56 and that of RSS method is 0.52. Here fuzzy performs better than TOPSIS by 17% and 21% better than RSS method. The balanced index of TOPSIS method has improved using Manhattan mobility than random waypoint mobility. From figure 5-8 (a), (b) and (c), it can also be seen that TOPSIS and RSS method does not use WiFi network but rather it loads WiMAX network the most. RSS method proves to be the worst in load balancing as it uses WiMAX network maximally and does not use WiFi network. Fuzzy method seems to utilize all the available resources to some extent.

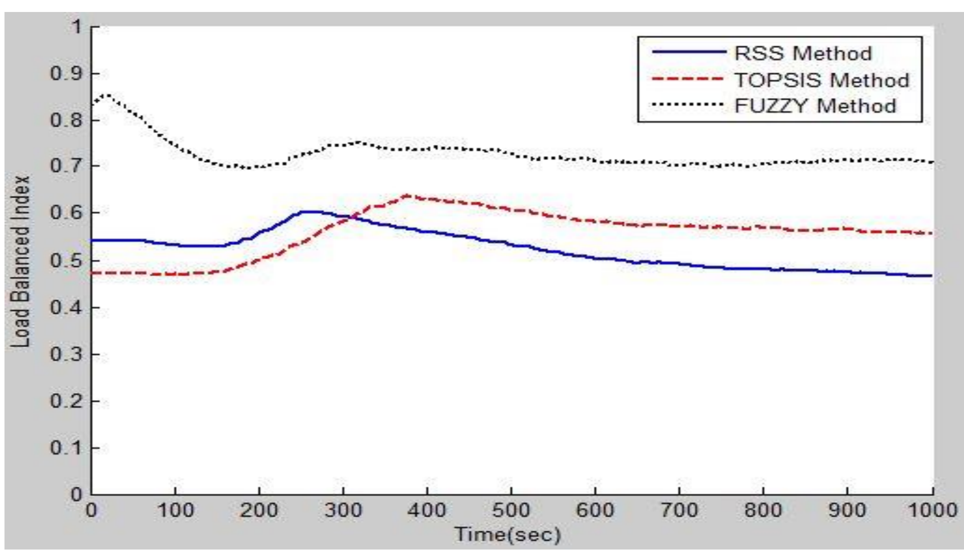
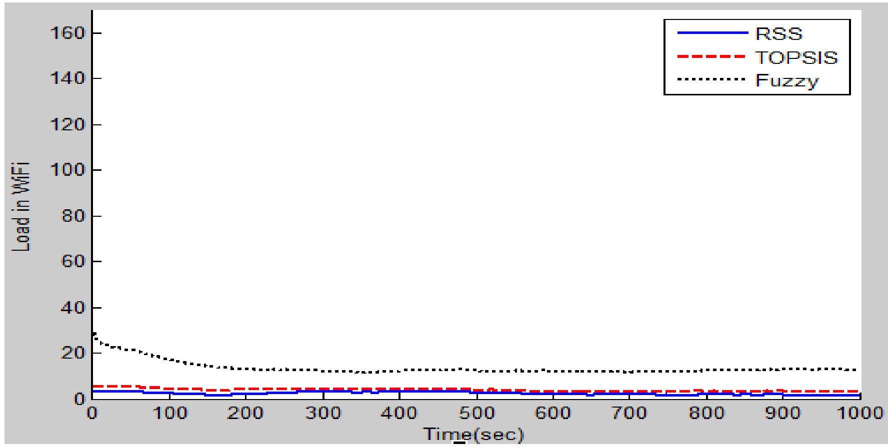
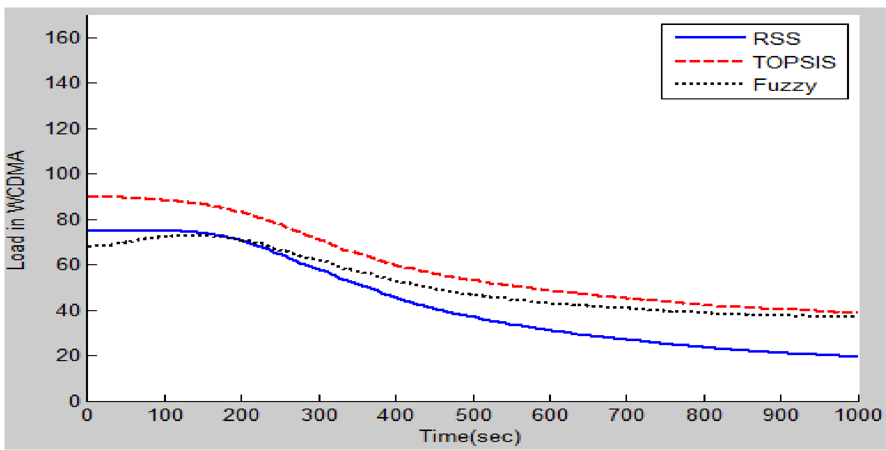


Figure 5-7 Balanced Index with respect to time for Manhattan mobility



(a)



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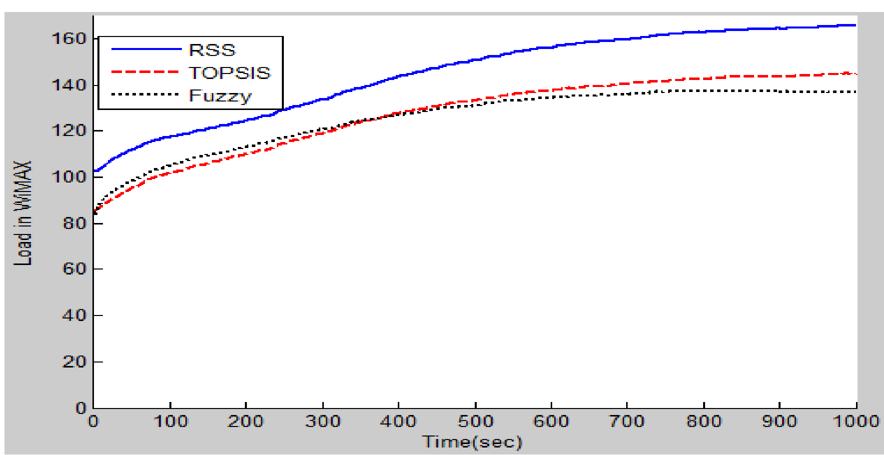

(c)

Figure 5-8 Number of user in (a) WiFi, (b) WCDMA (c) WiMAX network for Manhattan mobility

In the Manhattan mobility model used in this study, at the beginning of the users' mobility, the users move towards the center of the overlay until an intersection is met where the direction for further traversal is determined randomly. As the coverage of WiMAX network is better in the center region of the overlay, there is a rapid increment in loading of WiMAX network and rapid decrement in loading of WCDMA and WiFi network. The curve tends to level off as the time progresses. Due to this fact, at around 150-200 seconds the load balance index curve has a dip and then the curve tends to become more even. Similarly, as in the random mobility model case, the region of influence of WLAN is small thus the tendency of users moving out of WLAN is higher than entering into it; hence the fall in load distribution of WiFi network is seen at the beginning of the simulation before the load remains almost constant.

5.1.3 Blocking Probability

The bar chart for the number of successful handover execution to the blocked requests for random waypoint mobility model is presented in figure 5-9. The blocked requests for RSS based system is 2.56%, 4.08% for TOPSIS decision algorithm and 2.51% for fuzzy based algorithm out of the total successful handoff request that went to the respective network. The number of successful handoff request to the blocked request for different algorithms in Manhattan mobility model is shown in figure 5-10. The blocked requests in RSS method is 4.8%, and is 2.07% for TOPSIS and 3.07% for fuzzy method.

(a) (b)

Figure 5-9 Successful handover to dropped requests (a) random waypoint mobility (b) Manhattan Mobility

6 Conclusion

The comparison performed for two different mobility models, random waypoint and Manhattan mobility models, exhibits that only using RSSI as the sole factor for determining handover decision may cause overloading of the network with the highest transmitted power (good signal strength) and less signal strength networks to be extremely unused. Multiple criteria based decision algorithm seems more robust in terms of selecting the best network based on various base and mobile station parameters. Multicriteria fuzzy rule based decision algorithm shows better performance in utilizing available resources than other two methods. TOPSIS method shows a poor performance for random waypoint mobility but shows a better performance for Manhattan mobility in terms of load balance index. The rules in fuzzy system and the weights in TOPSIS method considered in this research are developed considering the strength of a parameter in influencing handover decision. More focus is mainly given to RSSI and mobile speed. These rules and weights may not be able to give an optimum solution in all network environments. An optimum values for the weights of the different criteria can be found using appropriate optimization method and proper network analysis. Also, the rules and membership functions of the fuzzy subsystems can be built using the genetic algorithms or the neural networks.

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