QUALITY OF SERVICE BASED VERTICAL HANDOFF IN HETEROGENEOUS WIRELESS NETWORKS

Thesis

Submitted in the fulfillment of the requirements for the award of the degree of Doctor of Philosophy

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Certificate

I hereby certify that the work which is being presented in this thesis, in fulfillment of the requirements for the award of the degree of DOCTOR OF PHILOSPHY submitted in department of Electronics and Communication Engineering, Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of Dr. Rajesh Khanna and refers other researchers which are duly listed in the reference section.

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

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ABSTRACT

The increasing demand of continuous end-to-end connectivity and the user desire for quality of service (QoS), while moving between different accesses technologies is a major challenge in heterogeneous wireless access networks. The issue in heterogeneous networks is to allow vertical handoff between pairs of different types of networks in the presence of Second Generation (2G), Third Generation (3G), Wireless Local Area Network (WLAN), Wireless Metropolitan Area Network (WMAN), satellite and Fourth Generation (4G) networks. The vertical handoff decision becomes critical when it is required for certain set of Quality of Service (QoS).

In this thesis, we have proposed an optimum and QoS based vertical handoff decision algorithms for heterogeneous networks. We have considered handoff between WLAN to Universal Mobile Telecommunications System (UMTS), WiMAX to UMTS and UMTS-WiMAX. The QoS concept encapsulates the idea that different data streams could be treated differently by the network depending upon the service being carried. QoS feature provides the required performance of latency, jitter and packet loss needed to support the service.

In the proposed work, a swarm based technique has been proposed for improving the QoS metrics for WLAN/UMTS/WiMAX networks. Swarm based technique is used to find out the best network in advance. A combined cost function is estimated by using the battery lifetime along with the metrics like Network Load, Data Rate, Received Signal Strength (RSS) and Signal-to Noise Ratio (SNR). The handoff is then executed by the serving Base Station (BS) that evaluates these QoS metrics to find a set of candidate target networks with demand of optimum QoS level. Based on analysis and comparison of results obtained with simulation work, it has been observed that proposed algorithm reduces the jitter, delay and improves QoS parameters.

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ABBREVIATIONS

AAA	Authentication, Authorization and Accounting
ACO	Ant Colony Optimization
AHP	Analytic Hierarchy Process
AIFSN	Arbitration Inter- Frame Space Number
ANFIS	Adaptive Neuro Fuzzy Inference System
AP	Access Point
ARA	Ant Colony Based Routing Algorithm
BA	Backward Ant
BE	Best Effort
BER	Bit Error Ratio
BS	Base Station
CAMMS	Context Aware Mobility Management System
CN	Cellular Network
CW	Contention Window
DCF	Distributed coordination function
DCP	Designated Crossover Point
DiffServ	Differentiated Services
DR-VADH	Data Rate Based Vertical Handoff
ESA	Exponential Smoothing Average
FA	Forward Ant
FBVAH	Fuzzy Based Vertical Handoff Approach
GPS	Global Positioning System
HHO	Horizontal Handoff
IEEE	Institute of Electrical and Electronics Engineers
IntServ	Integrated Services
LLT	Link Layer Triggers
LMDS	Local Multipoint Distributed Service
MCHO	Mobile Controlled Handoff
MICS	Media Independent Command Service
MIES	Media Independent Event Service
MIH	Media Independent Handoff
MIHF	Media Independent Handoff Function

MIIS	Media-Independent Information Service
MMDS	Multi-channel Multipoint Distributed Service
MN	Mobile Node
MPEG	Moving Pictures Expert Group
MT	Mobile Terminals
NCHO	Network Controlled Handoff
NRT	Non Real Time
nrtPS	Non-Real-Time Polling Service
PCF	Point Coordination Function
OQVHD	Optimal and QoS based Vertical Handoff Decision
PRSS	Predictive Received Signal Strength
QoS	Quality of Service
RFID	Radio Frequency Identification
RAT	Radio Access Technologies
RAN	Radio Access Networks
RSS	Received Signal Strength
RSA	Route-Selection Algorithm
RTT	Round Trip Time
RSSI	Received Signal Strength Indicator
RT	Real Time
rtPS	Real-time Polling Service
RANs	Radio Access Networks
SCTP	Stream Control Transmission Protocol
SI	Swarm Intelligence
SBVAH	Swarm Based Vertical Handoff Algorithm
SNR	Signal to Noise Ratio
SDR	Software Defined Radio
SAP	Service Access Points
SAW	Simple Additive Weighting
SR-VADH	Smart Routing based Vertical Handoff Approach
TCP	Transmission Control Protocol
UGS	Unsolicited Grant Service
UMTS	Universal Mobile Telecommunication System
VHC	Vertical Handoff Controllers

VHD	Vertical Handoff Decision
VHO	Vertical Handoff
VHSN	VHO Support Node
VADH	Velocity Adaptive Handoff Approach
WMA	Weighted Moving Average
Wi-Fi	Wireless Fidelity
WPAN	Wireless Personal Area Network
WLAN	Wireless LAN
WMAN	Wireless Metropolitan Area Networks
WBAN	Wireless Body Area Network
WWAN	Wireless Wide Area Network
WiMAX	Worldwide Interoperability for Microwave Access

Chapter 1

Introduction

1.1 Overview

The increasing demand of mobile user to have uninterrupted connection anytime, anywhere has led to our current efforts towards integrations of different wireless technologies. A network formed with integration of different wired and wireless technologies is known as heterogeneous network [1]. The thrust of mobile user for higher data rates, higher speed and Quality of Service (QoS) assurance are challenging issues in heterogeneous network. Different types of applications have different QoS requirements. Based on type of service, parameters in QoS are defined at the global level. These parameters include transit delay, throughput and error rate etc. Different combinations of latency, reliability and data rate are required to support different type of services [2]. Every service provider uses unique billing strategy for different services, as demanded by the user. Wireless communication is performed using wireless connectivity between network components to transmit and receive information. A wireless network is capable to provide network access to phones, computers, different applications, databases and internet within buildings. Besides this, wireless networks can be deployed with in campuses and even between remote locations, giving the user's ability to move, roam or work virtually from any location [3].

1.2 Classification of Wireless Communication Technologies

Various technologies used for wireless communications are radio-based, microwave-based, satellite-based and infrared-based free space optics. The large variety of wireless networks can be classified based on geographical coverage, level of mobility and spectrum allocation [4]. Based on coverage area, the wireless networks are classified as Wireless Personal Area Networks (WPAN), Wireless Local Area Networks (WLAN), Wireless Metropolitan Area Networks (WMAN) and Wireless Wide Area Networks (WWAN), as shown in Fig. 1.1.

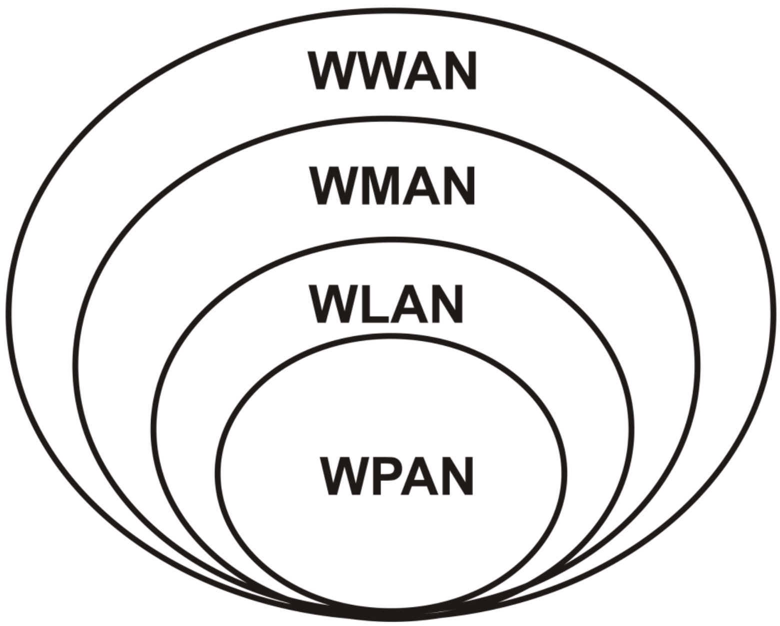

Fig: 1.1 Wireless Technologies Classification Based on Coverage

WPAN networks provide wireless connectivity to various devices and appliances within the limited area of a residence which is also known as home networking. It aims at integration and standardization between home end-devices and appliances. The main focus of WPAN is to facilitate the use of multiple PCs and peripherals, data interconnection, voice/video communications, music distribution and use of surveillance devices to command and control appliances such as meter reading, temperature and light regulation etc. Bluetooth is a main technology of WPAN. It is a cheaper technology, which requires low power and associated protocol stack to achieve short range wireless links between computers, notebooks, laptops and other portable devices. It operates at 2.4 GHz frequency with a maximum data rate of 3 Mbps [5]. Further, ZigBee is an enhancement of Bluetooth technology. It is based on Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 standard to control and monitor devices at low data rate radio communications and ultra-low power firmware resources. It's coverage range is from 1 to 100 m and is able to provide peak data rate of 128 Kbps.

Near-fields, is a sensor-based network also known as Wireless Body Area Network (WBAN). It is able to provide communications in near-field environments using Radio Frequency identification Device (RFID) and Ultra-Wide Band (UWB) transmission. RFID Frequency Identification is an example of a wireless RF, tag-based, low cost technology with no direct power consumption. It works in two modes, active and passive. In active mode there is requirement to make contact of wireless tag, whereas in passive mode it works wireless up to range of 5 meters. RFID is used in number of applications today for identification of particular item and it is used instead of line-of-sight and laser-based bar code systems. RFID is very useful to provide a network of radio-based sensors and actuators in industrial automation and control networks [6].

In home or office it is difficult and costly to deploy wired connection for interfacing number of devices such as desktop PC, laptop printer, internet connection from broadband. WLAN is a better option to connect all such device within 50 to 100 m radius area. Thus, it provides wireless local data and voice access to shared resources such as servers, printers and routers within a limited area of an organization or business [7]. WLAN is very successful today in the retail, manufacturing, education, health care sectors and in hot areas such as airports, small/home offices, internet cafes and even in residential homes. It is based on short-range RF communications, standardized by the IEEE working groups. WLAN provides freedom to physically move and allows the users to roam around within a small coverage area as well as connect through an access point to the network. A data rate up to 54 Mbps and a typical range of 3 m to 300 m is supported by this technology [8]. The main specifications are standardized as IEEE 802.11a, IEEE 802.11b and IEEE 802.11g. The WLAN IEEE 802.11b called wireless ethernet is widely used technology. Now a days, the entire family of IEEE 802.11 a/b/g falls under the term Wireless Fidelity (Wi-Fi) [7, 8].

WMAN network provides direct broadband access and fixed wireless network connectivity within metropolitan areas. The initial WMAN technologies were Local Multipoint Distributed Service (LMDS) and Multi-channel Multipoint Distributed Service (MMDS). LMDS is a fixed broadband wireless technology based on directional antennas working in the microwave spectrum of 28–40 GHz. It requires line-of-sight transmission between transmitters and receivers. WMAN is used to exchange broadband local loop services for residential and business customers. It operates in the 2.5, 3.5, 5.3, 5.8 GHz spectrum [9]. Enhanced WMAN technology is able to support data rate up to 70 Mbps and it is known as Worldwide Interoperability for Microwave Access (WiMAX). WiMAX is able to provide coverage of radius 30 miles (50 km) with wireless access [10].

WWAN is used to provide direct network connectivity to large areas including distant remote sites [11]. WWAN is the largest family of mobile radio cellular networks spanning three solid generations first generation (1G), second generation (2G), third generation (3G) with various mobile technologies and service implementations. WWAN support voice and data services and is able to provide data rates up to 2 Mbps for a range of 50 km. Cellular mobile systems are integrated with ground-based equipment and are able to connect directly with horizontal RF-based wireless connectivity. New generations of satellite communications technologies allow direct phone-to-phone global area communication [12].

1.3 Need of Heterogeneous Wireless Network

The fundamental idea of mobile communications is that continuous communication is maintained while the mobile user is moving through the coverage area. To maintain this coverage, integration and convergence of technologies is required to form a heterogeneous network [13]. Heterogeneous network environment is very useful to provide the coverage and capacity needed for various Radio Access Technologies (RAT). Heterogeneous network is typically composed of a variety of formats of base station, Radio Access Networks (RAN), transmission solutions and power levels.

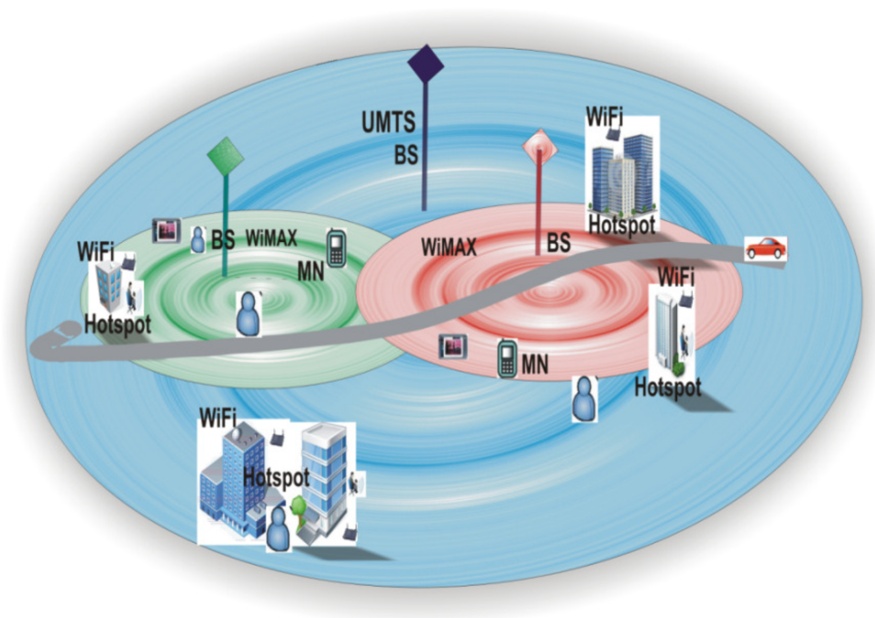

Fig: 1.2 Heterogeneous Network Environment

The Fig. 1.2 depicts an environment including Universal Mobile Telecommunication System (UMTS), WiMAX and WLAN technologies. In this figure one UMTS Base Station (BS), two WiMAX Base Stations (BS), and four Wi-Fi hotspots have been shown. A mobile user in a car is initially connected to UMTS network at home.

Horizontal as well vertical handoff will take place if the user moves from home to office. The user may choose between his home Wi-Fi network and the network of his cellular operator. To start a voice call, the user selects a Wi-Fi access due to the lower service cost. Continuing the call, the user leaves the home network and his terminal must automatically recognize signal strength degradation and reconnect to the same service via cellular network.

With complementary characteristics of various wireless network technologies, heterogeneous access networks offers overlapping coverage to mobile users in order to provide both high bandwidth and good coverage over a range of geographical areas. Cooperation of different networks is required for heterogeneous wireless network integration. In heterogeneous environment RAN are supposed to provide low bandwidth applications over a wide geographic area and high bandwidth over a limited geographic area [14].

1.4 Handoff Issues in Heterogeneous Wireless Technologies

Handoff is the process of transferring ongoing calls from one network to another network as the MN is moving within the service area. The handoff or handover are interchangeable terms. The transfer is also affected by temporary congestion within a particular cell when call processing must be handed off to a less busy cell [19]. The heterogeneous network formation is focused to use the best and unique features of various technologies. Due to difference in architecture and protocol of wireless technologies, there is an issue of compatibility and convergence. Along with selecting best access network, perfect handoff decision and keeping communication session active, the QoS level is also required to be maintained [15]. Moreover, a user should be able to find services as well as QoS, mobility and security support provided before being attached and authenticated to a network. Wireless access networks in the same geographical location may compete. For example, a Wi-Fi network may advertise QoS support without really providing it. A mobile node should be able to connect within cellular and Wi-Fi network, the latter due to the lower service cost for appropriate capabilities [16]. A handoff can be a Vertical Handoff (VHO) or Horizontal Handoff (HHO). The received signal strength is a major factor that is used traditionally for handoff decision making process. If the Received Signal Strength (RSS) falls below a predetermine threshold level and also smaller than the sum of hysteresis & new signal strength , then the horizontal handoff is said to be triggered. RSS plays an important role in determining the horizontal handoff. However, this is not true for vertical handoffs as RSS is not the only factor that reflects the network conditions because different networks are not comparable on the basis of RSS in heterogeneous environment. The type of service, cost, network condition, performance of system, mobile node condition and user preference are the new metrics required for hybrid networks use in conjunction with RSS measurements [17]. The parameters related to network such as network latency, available bandwidth, traffic and congestion, are required for effective network usage to be monitored. Various parameters such as path loss, channel propagation characteristics, Signal to Noise Ratio (SNR), inter channel interference and Bit Error Rate (BER) is required in the handoff process, for the system performance to be maintained. MN parameters such as velocity, moving pattern, moving histories, and location information are needed to be considered for better handoff [18]. A user preference is defined as special requests for one type of system over another. Based on user preference other research issues in heterogeneous network environment are shown in Fig. 1.3.

Fig: 1.3 Issues Based on User Satisfaction

Handoffs may also take place when the caller is switched from one type of technology to another or from one mobile operator to another as a part of roaming. Mobility management is a challenging issue for roaming user to support and access various services on progress through different access technologies. There are two types of mobility management scenario, which enables communication in heterogeneous networks. First is known as static scenario, which locates MN in order to deliver data packets and second is dynamic scenario to maintain connections with MN moving into new areas. Resource and connection management is further classified as location management and handoff management. Location management is process to locate a MN, track its movement, and update the location information [20]. On the other hand, handoff management is focused mostly to control the change of a MN's Access Point (AP) during active data transmission. To maintain the service continuity in different cell site, there are two types of handoffs, hard handoff and soft handoff as shown in Fig. 1.4. Hard handoff takes place when the connection to the original cell site is dropped before the connection to a new site is established. Since this handoff process is very short taking less than approximate 250 ms, so it is hardly noticeable in voice conversations.

The soft handoff occurs when the connection to a new cell site takes place before forming the connection to the original cell site is broken [21].

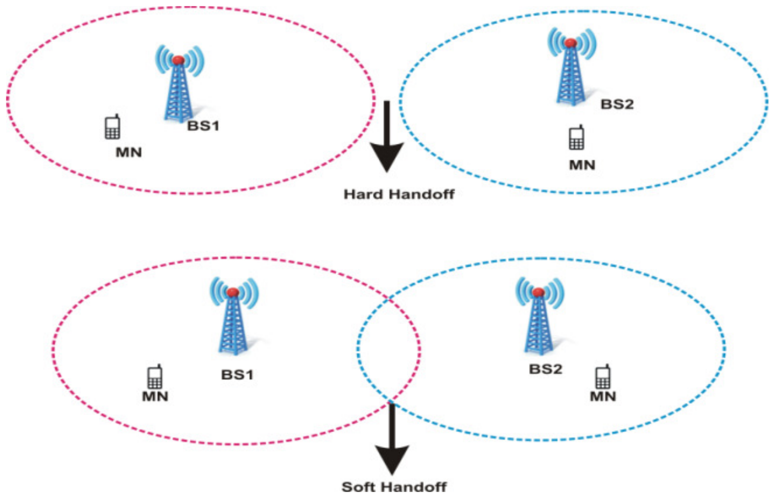

Fig: 1.4 Hard Handoff and Soft Handoff

As shown in Fig 1.5, horizontal handoff is initiated and executed with in same standard network technologies i.e. WLAN to WLAN (or WiMAX to WiMAX). In case of vertical handoff, the communication is transferred from one type of network to other type i.e. WLAN to WiMAX (or WiMAX to UMTS) as shown in Fig. 1.5. The vertical handoff is further classified as downlink vertical handoff and uplink vertical handoff.

The switching of control signals from lower layer to higher layer is known as uplink VHO and from higher layer to lower layer it is known as downlink VHO [23]. The three main steps of traditional handoff process are handoff decision, radio link transfer and channel assignment. Mobile Controlled Handoff (MCHO) and Network Controlled Handoff (NCHO) are different handoff techniques. In NCHO the handoff decisions are taken by the network while in MCHO, the handoff decision is made by the mobile node itself by measuring its own signal strength.

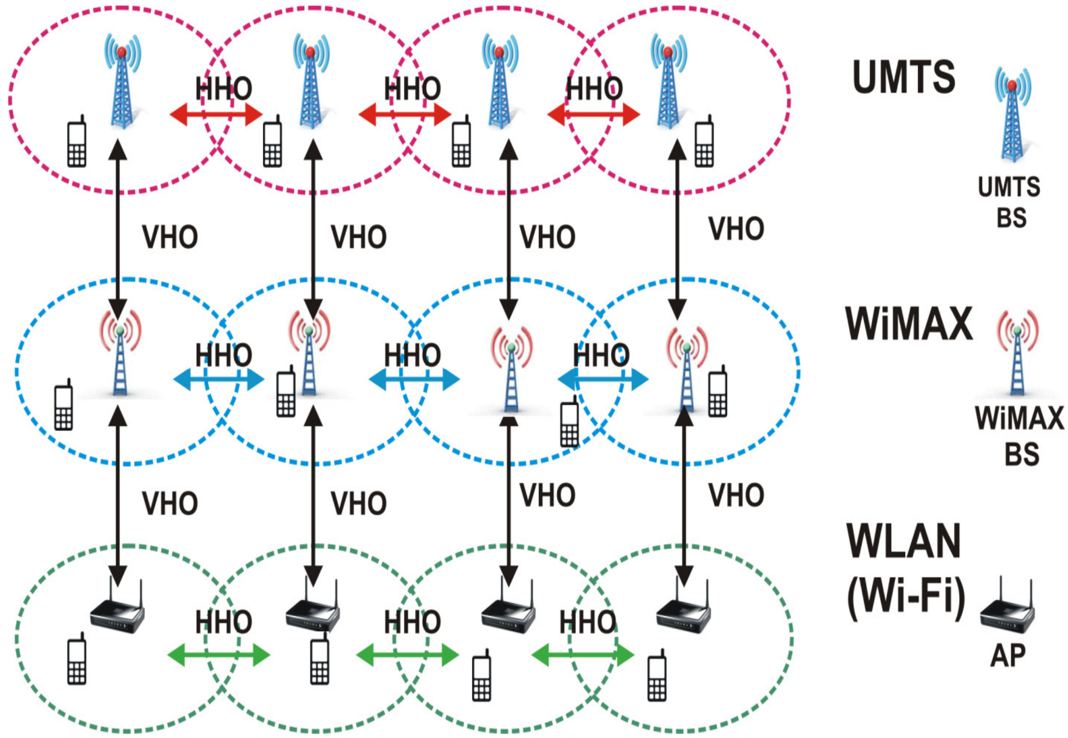

Fig: 1.5 Vertical Handoff and Horizontal Handoff

1.5 Quality of Service in Heterogeneous Networks

There is requirement of different QoS parameters such as latency, bandwidth, data delivery etc. for various applications and users expectations. For example, low latency is required for IP telephony, guaranteed bandwidth for streaming audio and video, predictable delivery for collaborative interactive service, protection of network control for different grades of services from competing users and minimum guarantee of service quality to meet user expectations [24]. All applications lead to definition of QoS which can further be classified as application level QoS and network level QoS. An application level QoS is basically the user perceived QoS and has to completely satisfy user's expectations. Network level QoS is based on tangible measurements of factors such as delay, bandwidth, and packet loss. The network implementation is a challenging issue in order to support different grades of services with some performance guarantees. Issues that play important role in the network level QoS implementations are QoS specifications of individual flows, network bandwidth resource management, admission control, QoS verification of individual, aggregated flows, traffic policing, packet forwarding mechanisms and a QoS routing mechanism that satisfies the given QoS constraints [25]. A service is a function provided by a service provider to the subscriber of that service. QoS is a measure of service quality to the customer. The measurement of quality is based on service parameters or QoS metrics [26]. Service parameters are values with significance for both the service provider and the subscriber. The difficulty of using service qualifiers comes from the fact that the same parameters can have different significance to the user than to the provider. The service parameters can be categorized as quantitative, qualitative and relative. As shown in Fig. 1.6, the quantitative parameters are measurable in absolute terms. However, parameters that can be easily measured might not be relevant to the user. Parameters significant to the subscriber might not be easily measured. Qualitative parameters are subjective to perceptions regarding the service intelligibility, manageability, security or signal strength in broader terms or categories such as strong, moderate or weak. Relative parameters are used for comparison to measurable service parameters in terms of higher, equal or lower than a known parameter [27].

These parameters are all valuable indications of the ability of the service provider to restore the service in case of outages. Outages are caused by physical failures of network components, software errors. QoS parameters are collected by managing functional areas covering physical layer, bandwidth, traffic, policy, and applications [28].

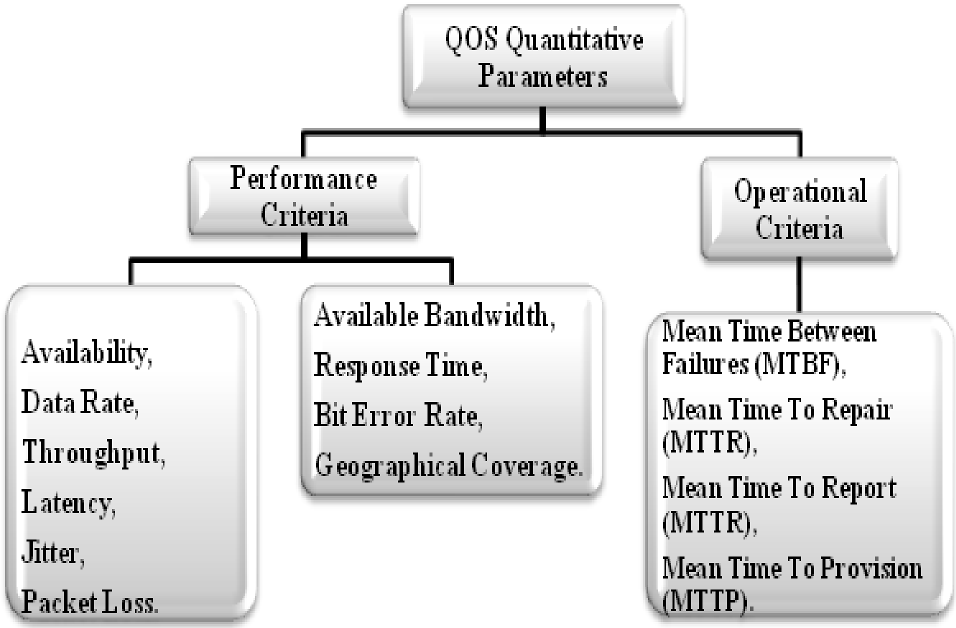

Fig: 1.6 Quality of Service parameters

The focus of this research work is the real time and non real time applications such as streaming multimedia applications as these applications require fixed bit rate and are delay sensitive. Combining WLAN, WiMAX and UMTS technologies creates a ubiquitous wireless network with local hotspots to supply the user with high speed services.

1.6 Research Motivation

With convergence capability and characteristics compatibility of various wireless access networks, the thrust of mobile user in terms of QoS provision, mobility management and security support can be satisfied. For seamless mobility, compatibility of technologies, resource management and handoff decision criterion are very important issues in heterogeneous network.

An UMTS-WiMAX interworking architecture based on 3GPP standards has been proposed for handoff to control packet loss and interruption time [42]. Network initiated handoff approach is proposed to provide the QoS service continuity in UMTS/802.16e networks [64]. An interworking sub layer at layer 2 on RNC, W-RNC and UE is proposed to provide a seamless PS inter-RAT handoff between UMTS and WiMAX [65]. In proposed approaches, technical details such as network bandwidth, mobile speed, and delay estimation, as well as load balancing were not fully addressed.

Handoff criteria for the integration of UMTS and WLAN based on combined receiving SINR has been proposed, which provides the knowledge of the achievable bandwidth from both access networks [77]. The proposed approach has introduced increased handoff delay with excessive handoffs and ping-pong effect [79]. The route discovery is performed based on traditional method that increases the delay and overhead. A novel network selection approach is presented for the integration of UMTS and WLAN to always guarantee the best QoS through selecting the most suitable network while preventing frequent handoffs [37]. Optimal handoff control is very important for investigating the possibilities of handoff optimization by providing mobile terminals with additional information about the target system [62]. A MDP based approach has been proposed, which is based on different link reward functions assigned to various applications and networks. The proposed MDP approach results are compared for reward and number of handoff only [58]. In proposed scheme for WLAN and UMTS handoff QoS parameters in terms of jitter, delay and throughput are not evaluated. Optimization based on additional parameters such as bandwidth and velocity with goodput estimation can be further investigated.

A handoff between WiMAX and WLAN with high bandwidth but weak received signal is not desirable as it may result in connection breakdown [24]. Increased connection breakdown probability without considering the RSS is observed in algorithm [78]. A traveling distance prediction based method based on RSS is used to recalculate and refine the estimations for velocity to improve the performance inside the WLAN cell

[59]. The proposed approach selects the optimum BS or AP based on load and battery power, without considering the velocity.

Although there have been various vertical handoff algorithms for WLAN/WiMAX, WLAN/UMTS and UMTS/WiMAX available in the literature, our work is motivated by QoS aspects at the time of handoff. First, we have focused on best network selection based on network load and speed of mobile node during the vertical handoff decision. Second, we have focused seamless handoff to maintain QoS during the vertical handoff execution.

1.7 Objective of thesis

Based upon the review and identified gaps, the objectives of the research work have been formulated and are listed below:

1. **To study existing VHO algorithms for interworking between WLAN/WiMAX/UMTS.**
2. **To propose algorithms for VHO with better QoS between two interworking technologies i.e. WLAN/WiMAX, WLAN/UMTS and WiMAX/UMTS.**
3. **Performance evaluation of the proposed algorithm.**

1.8 Organization of the Thesis

The work presented in this thesis mainly incorporates the improvements in the QoS from user perspective in heterogeneous network environment. The thesis contains six chapters describes as follow:-

Chapter 1- is an introduction of QoS requirement in wireless technologies with mobility support.

Chapter 2- provides guidelines which affect the research such as background for the research area as well as its objective. In this Chapter, we have addressed technical specifications of technology involved in research work. For an integration of various technologies to create a heterogeneous network environment compatibility of architecture and protocols are required. We have discussed QoS support for various types of application for WLAN, WiMAX and UMTS. The literature work for an integration of WLAN/WiMAX, WLAN/UMTS and WiMAX/UMTS has been discussed. The QoS support of WLAN, WiMAX and UMTS is presented. Different interworking architectures have also been discussed. Issues of mobility management are still at novice stage. There are number of issues that have to be resolved to obtain seamless mobility. For example, issues of security, mobility management, network selection are to be addressed properly for heterogeneous networks as the operating parameters surrounding these networks differs.

Chapter 3- presents an overview of IEEE 802.21 standard Media Independent Handoff (MIH) support for integration of various technologies. Various protocols used in MIH have been discussed to integrate technologies such as WLAN, WiMAX and UMTS. A Fuzzy based handoff approach has been presented, for vertical handoff decision in WLAN and WiMAX technologies. Swarm based vertical handoff approach is discussed in next section for vertical handoff in WLAN-WiMAX. To evaluate our solution, we have implemented an appropriate simulation environment. Simulation engine NS-2 version 2.29 with NIST add-on modules has been used. The results for proposed and other approaches have been analyzed and compared for QoS parameters such as end to end delay, jitter and throughput.

Chapter 4- involves details of proposed aspects of inter-working between WLAN and UMTS technologies in terms of handoff, more specifically requirements to perform a handoff and execution procedure of handoff. The different approaches are: addressing the multicriterion decision problem provided in the literature, estimating the combined cost function using the battery lifetime along with the metrics like load, velocity of mobile node, Received Signal Strength and Signal-to Noise Ratio. The handoff is then executed by the serving BS that evaluates these QoS metrics to find a set of candidate target networks, guaranteeing the optimum QoS level.

Chapter 5- gives details of the proposed aspects of inter-working between WiMAX and UMTS technologies. This chapter depicts an idea as how to simulate the proposed optimal and QoS based swarm based technique. To evaluate our solution, we have implemented an appropriate simulation environment. Simulation engine NS-2 version 2.29 with NIST add-on modules has been used. To simulate a realistic mobility scenario, we have used the well-known mobility emulator to compel the movement of MN's and have used it in the simulation platform. We have created several multi-interface MN's that move within a defined area following the generated movements trace file. During their move, MNs are always within the range of one or several wireless access networks (i.e., WLAN, WiMAX and UMTS) and are also able to detect and select best themselves. Simulation results demonstrate that the proposed swarm based technique performs well with respect to QoS parameters handoff delay, throughput and jitter etc. We have compared our proposed Optimal and QoS based Vertical Handoff Decision (OQVHD) with the Route-Selection Algorithm (RSA).

Chapter 6- concludes the thesis and hence, intended to summarize not only the course of this research, as well as enlist future steps. In this thesis, we have proposed an optimum and QoS based vertical handoff decision algorithm for heterogeneous networks and studied existing VHO algorithms for interworking between WLAN/ WiMAX/ UMTS. More precisely, this chapter presents the concluding remarks of the research developed during this thesis.

In the next Chapter, a review of various vertical handoff algorithms for based on different parameters is presented for heterogeneous network considering. QoS support of WLAN, WiMAX and UMTS has also been discussed. The main focus of this Chapter is to present the literature review of vertical handoffs in WLAN/WiMAX, WLAN/UMTS and WiMAX/UMTS networks.

Chapter 2

Background and Literature Review

2.1 Overview

Evolving networks many times treat different type of traffic data in a similar way. Different types of data have different traffic priority, delay and packet loss requirements. In real time applications, if the latency or the loss rate exceeds certain level it degrades the Quality of Experience (QoE) and QoS. In contrast non real time services such as file transfer are able to tolerate a reasonable amount of delay or loss without much degradation of QoE and QoS. In this research work, three different technologies WLAN, WiMAX and Universal Mobile Telecommunication System 'UMTS' (defined by 3GPP [5]) are considered in heterogeneous network environment. The characteristics of these technologies are shown in Table 2.1.

Table 2.1: Characteristics of WLAN, WiMAX and UMTS

	WLAN	**WiMAX**		**UMTS**
Standard	IEEE 802.11	IEEE 802.16e	IEEE 802.16d	IMT 2000
Channel Width	Fixed 20MHz	Variable ≤ 20 MHz	Variable ≤ 28 MHz	5 Fixed 5 MHz
Spectrum	2.4 to 5.2 GHz	2 to11 GHz	10 to 66 GHz	~ 2 GHz
Data rate	2/54 Mbps	70 Mbps	240 Mbps	1/14 Mbps
Range	100 m	1-7 km	12-15 km	50 km
Multiplexing	TDM	FDM/TDM	FDM/TDM	FDM
Transmission	OFDM	OFDM/OFDMA	SC	WCDMA
Mobility	Pedestrian	Vehicular (802-16e)	No	Vehicular
Advantages	Throughput And costs	Throughput And range		Mobility And range

The capability to provide resource assurance and service differentiation in a network is often referred to as QoS [6]. QoS has the capability of providing resource assurance service differentiation in a network. Reliability, delay, jitter and bandwidth can characterize the requirements for each type of traffic flow. For new wireless applications resource assurance is critical. The QoS solutions are predominantly provided by the Integrated Services (IntServ). Differentiated Services (DiffServ) focus on the IP layer and these layers are expected to configure such IP based service requirement. The following section addresses the specification and provisioning of underlying QoS-based requirements for wireless local area networks (WLANs), Wireless Metropolitan Area Networks (WMANs) and Wireless Wide Area Network (WWAN) (3G) architectures [3-6].

2.1.1 Quality of Service in WLAN

QoS in WLANs can be characterized in two ways as parameterized QoS and prioritized QoS. The IEEE 802.11 MAC architecture has Distributed Coordination Function (DCF). DCF only allows best effort services and does not provide QoS for multimedia applications [3]. In DCF there is no differentiation mechanism to support high priority applications to have optimum values of jitter, delay and bandwidth. Point Coordination Function (PCF) is designed to support time bound multimedia applications. The PCF polling schemes is inefficient and complex for higher priority service class. IEEE 802.11 TGe, which is the extended form of IEEE 802.11 MAC, provides different types of class services access based on security, and authentication to support multimedia applications. 802.11TG is based on the enhancement ability of a physical layer in order to deliver the critical multimedia applications with the best effort data service. It has Hybrid Coordination Function (HCF) and Enhanced DCF Channel Access, which has capability of prioritizing QoS. It also has HCF Controlled Channel Access (HCCA) for prioritizing QoS with a contention free period, direct communication in infrastructure mode, Access Point (AP) mobility and MAC-level FEC (forward error correction).

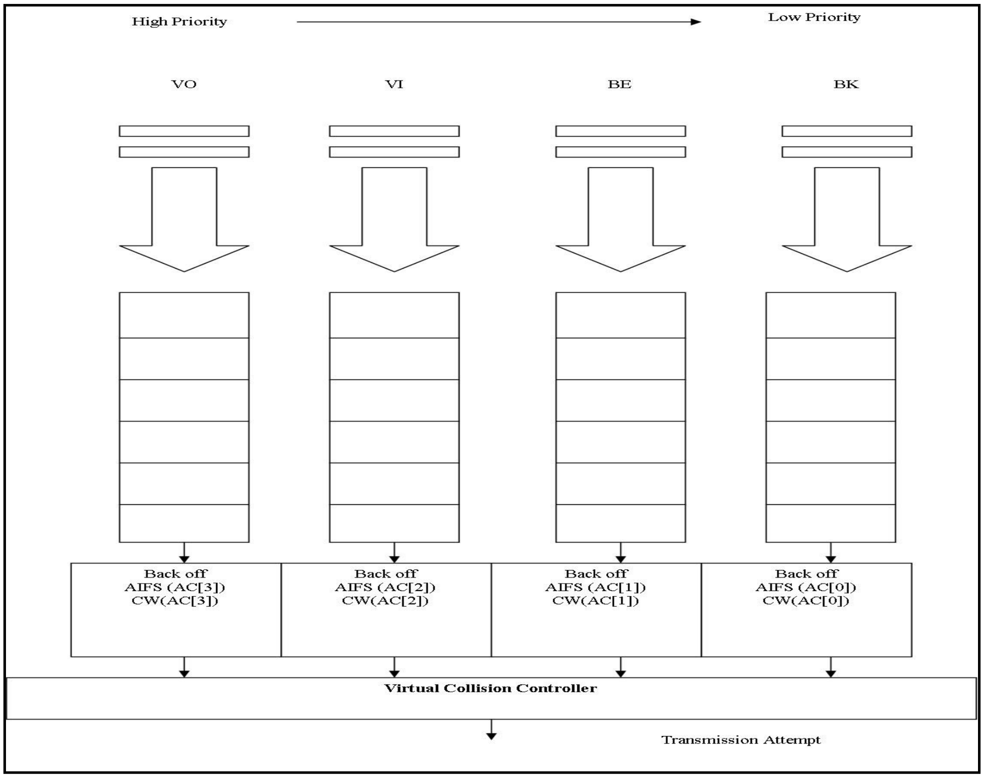

Fig:- 2.1 Quality of Service in WLAN [3]

As shown in Fig. 2.1, there are four priority service classes such as Video (VO), Voice (VI), Best Effort (BE) and Background (BK) in WLAN, assuring a consistent QoS mechanism across wired and wireless network. Different fixed random periods for various wireless applications are allocated by Wi-Fi Multi-Media (WMM) specifications for providing prioritization categories. There are two types of interval classification in WMM: fixed and random. Arbitration Inter Frame Space Number denoted as 'AIFSN' is a fixed waiting interval. The random interval is called the Contention Window 'CW'. Both intervals are expressed in time slots and each helps to avoid collisions of packets belonging to the same category while giving a chance to each multimedia application to exchange information with minimum delay. QoS support and vertical handoff possibility in WLAN, gives integration assurance with other technologies in heterogeneous network [6-7].

2.1.2 Quality of Service in WiMAX

Wireless metropolitan technology & network design that is based on the IEEE 802.16d-2004 version for fixed wireless MAN standard specifications is named as Worldwide Interoperability for Worldwide Access (WiMAX) by the WiMAX Forum. This name also refers to the IEEE 802.16e-2005 version for the Mobile Wireless MAN standard specifications. The IEEE 802.16e standard is enhancement of IEEE 802.16 a/b/c/d standard to develop mobility support and QoS. QoS classes and QoS parameters are defined in order to build QoS management into the WiMAX standards. QoS classes are related to time sensitive applications that includes voice and video communication. In order to meet the QoS requirements of multimedia applications four different scheduling services are specified by the 802.16 a/b/c/d MAC that involves: Unsolicited Grant Service (UGS), Real-time Polling Service (rtPS), Non-real-time Polling Service (nrtPS) and Best Effort (BE). Each service is characterized by set of QoS parameters that meet the requirement of applications. WiMAX scheduling services consist of certain main characteristics that are fast data schedules, frame scheduling, dynamic resource allocation.

2.1.3 Quality of Service in UMTS

For widespread vehicular and pedestrian services the UMTS belongs to higher tier digital cellular communication system and it always provides on ubiquitous connectivity for subscribers. UMTS transmits the data with transmission rate up to 14 Mbps. In UMTS various applications are supported with different bandwidth and QoS requirement**.** Traffic generated by data transfer services and internet access is bursty and unpredictable. Data transmission between machine is loss sensitive i.e. not sensitive to end to end delay or jitter. It is required to have strict limits on the transmission delay in order to run the real-time applications but it can cope with reasonable loss rates. For example, end-to-end delay for voice must be less than 400 ms, even with echo cancellation. For user interested in the end-to-end QoS perceived at application level, it is essential that the system uses the transmission resources efficiently. As shown in Fig. 2.2, the QoS support is based on the hierarchical structure defined in 3GPP specification TS 23.107 [6]. The objective of this first separation is not limiting, neither the terminal equipment type nor the possible external networks (e.g. Internet) with which we can communicate. The first section is defined as the connection between the user's Mobile Terminals (MT) and the core network edge node (an MSC or an SGSN). This UMTS QoS architecture is very useful for QoS provision. The air interface, the Universal Terrestrial Radio Access Network 'UTRAN' and the Iu interface are involved in the Radio Access Bearer 'RAB' service [5]. This QoS profiles in UMTS is in the form of network locations presenting more scarcity of bandwidth. On the other hand, the Core Network (CN) services located in CN edge and the CN gateway node are useful for the external network access.

UMTS supports five service classes traffic class, conversational class, streaming class, interactive and background class. In order for UMTS to deliver multimedia services via the Packet Switched (PS) domain, QoS (particularly IP QoS) needs to be supported. Unsolicited Grant Service (UGS) is designed to support real-time applications that generate fixed-size data packets at periodic intervals, such as T1/E1 and Voice over Internet Protocol (VoIP) without silence suppression. rtPS is designed to support real-time applications that generate variable size data packets at periodic intervals, such as Moving Pictures Expert Group (MPEG) video and VoIP with silence suppression like

UGS and rtPS scheduling services, nrtPS and BE are designed for applications that do not have any specific delay requirement [24]. The main difference between real time and non real time PS is that nrtPS connections are reserved for minimum amount of bandwidth which can boost performance of bandwidth intensive application, such as FTP.

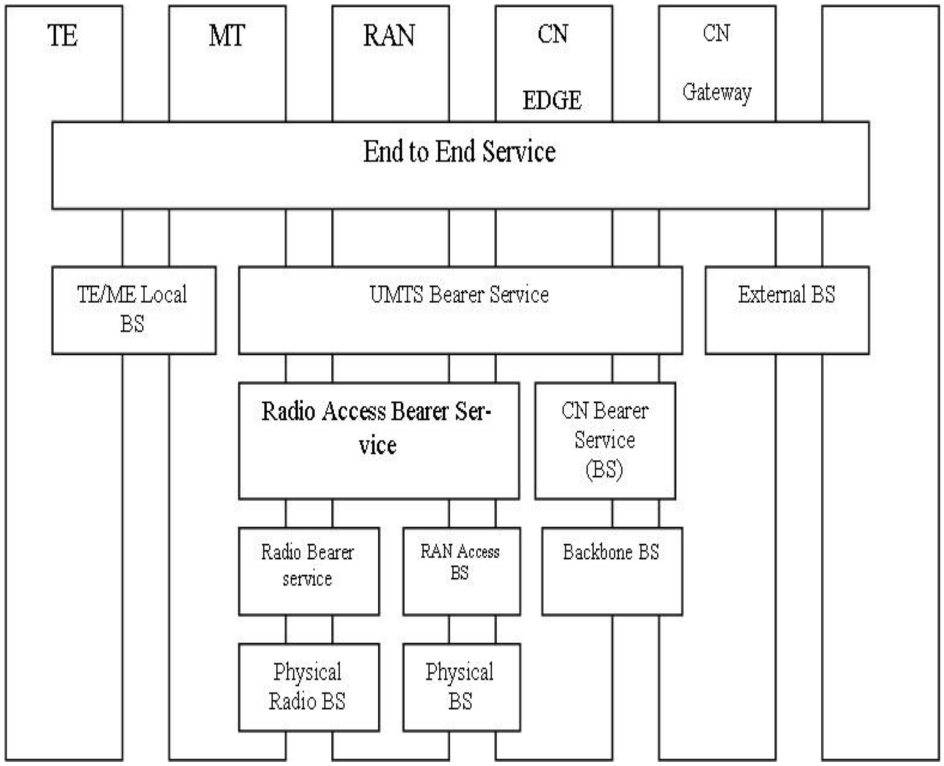

Fig: 2.2 Quality of Service Architecture for UMTS (3GPP, TS 23.107)

2.2 Literature Review

As one standard of Third-Generation (3G) cellular networks, UMTS supports universal roaming within one cell that covers up to several square kilometers and can be integrated with other networks such as WLAN and WiMAX [8-14]. There are two categories of integration of UMTS with WLAN and WiMAX, tightly and loosely coupled architectures. In a tightly coupled architecture, WLANs and WiMAX networks are integrated with 3G/UMTS networks. The WLANs and the WiMAX networks can be integrated through a 3G logical node and these networks behave as alternate of RAN connected with the 3G/UMTS network. WLAN operates as a virtual RAN in the cellular system, if we consider the tightly coupled architecture. The data traffic in WLAN is required to pass through cellular network in order to connect to the internet. UMTS Authentication, Authorizations & Accounting (AAA) is responsible for connecting gateways with the internet. There is no direct link to the 3G/UMTS network equipment. For making handoff decisions, RSS is a traditional and indispensable factor for consideration [32].

Different types of services require various combinations of reliability, latency, and data rate. Cost is always a major consideration to users, as different networks may employ different billing strategies that may affect the user's choice of handoff. The wrong cell detection algorithm has been devised in [33], which can reduce the occurrence of handoffs to wrong cells. User preferences can be used to cater to special requests for one type of system over another. A multi weighted algorithm for computing priorities of handoff requests, was proposed to serve arriving multiclass calls with highly diverse QoS parameters [34]. To guarantee the system performance, a variety of parameters can be employed in handoff decision, such as the channel propagation characteristics, path loss, inter channel interference, signal-to-noise and bit error rate. A virtual connectivity based mobility management scheme is presented using the end-to-end principle [35]. Mobile node conditions include dynamic factors such as velocity, moving pattern, moving histories and location information. For fast moving users, mobility management scheme is proposed, combining hierarchical micro-mobility with fast handoff and vertical handoff mechanisms to reduce the overheads [36].

Frequent handoffs degrade the QoS during vertical handoff. A novel network selection scheme is presented for the integration of UMTS and WLAN to always guarantee the best QoS through selecting the most suitable network while preventing frequent handoffs [37]. An architecture of integrated WLAN and Wireless Wide Area Networks (WWAN) has been proposed based on mobile Internet Protocol IPv6 [38]. Radio Access Technologies are connected by two methods: loose coupling and tight coupling. A vertical handoff scheme is presented between 'WWAN' and 'WLAN', based on tight coupling [39]. A technique has been proposed with minimum energy consumption and maximum bandwidth utilization [40].

Based on specified user preference, unreliable environment conditions and QoS requirements a handoff mechanism has been developed [41]. Fluctuation of RSS and interruption delay is due to improper handoff decision degrade parameters like handoff execution time. Based on 3GPP standards handoff procedure, a UMTS-WiMAX interworking architecture has been proposed, which promises low packet loss and low interruption time [42]. Network-related parameters such as traffic, available bandwidth, network latency and congestion need to be considered for effective network usage [43]. An approach including the call admission control, resource reservation mechanism for real time services and fuzzy controllers has been proposed to adjust bandwidth of real time service [44]. A bandwidth adaptation algorithm has been proposed to evaluate the inherent goodness of exploiting forced vertical handoffs [45]. Movement Aware Vertical (MAV) handoff algorithm is responsible for avoiding unnecessary handoff by adjusting the dwell time adaptively and also by predicting the residual time in the cell of target base station [46]. MAV handoff algorithm allows an MN to select better connection based on adaptive dwell timer. Based on user data rate and load condition, a multi standard radio resource management is proposed for heterogeneous networks [47].

A terminal controlled mobility management and network selection which is user centric, power-saving, cost-aware, and performance-aware is presented [48]. The authors have proposed a novel error recovery scheme called Sending-buffer multicast aided retransmission, with fast retransmission to improve performance during VHO and have also proposed a new analytical model for Stream Control Transmission Protocol (SCTP) [49]. The authors addressed wireless profiled Transmission Control Protocol (TCP) premature timeouts and also proposed two proactive schemes, called Round Trip Time (RTT) inflation and RTT Equalization [50]. An analytical framework for studying the performance of Wireless Profiled TCP (WP-TCP) flows over the integrated wireless LAN and cellular networks has been presented [51]. A new architecture has been proposed for network assisted management of vertical handoffs that aims at achieving the most relevant intersystem mobility decision [52]. Based on handoff delay and signaling load, a Vertical Handoff (VHO) solution has been proposed to optimize mobility management over heterogeneous networks [53]. Based on the optimization of a channel access strategy for a cognitive multi-standard radio node handoff, a packet-by-packet vertical handoff to improve the performance of unlicensed spectrum access has been proposed [54]. A novel scheme called Designated Crossover Point (DCP) within the existing IP end-to-end Quality of Serve architecture has been proposed to execute a seamless handoff [55]. An application layer solution for mobility management is based on the SIP protocol [56]. It also satisfy's the important necessary requirements for the proper implementation of vertical handoff. A cross-layer-based polynomial regression predictive RSS approach has been proposed with the MDP-based optimal network selection [57]. Based on the MDP formulation, a link reward function is used to model the QoS of the mobile connection [58]. A traveling distance prediction based method with RSS has been proposed to improve the performance inside the WLAN cell [59].

The authors have proposed an adaptive multiple attribute vertical handoff decision algorithm that enables wireless access network selection at a mobile terminal using fuzzy logic concepts and a genetic algorithm [60]. A software defined radio 'SDR' framework based solution is presented to allow coexistence of WiMAX /UMTS technologies [61]. A VHO Support Node (VHSN) which is attached locally to the wired LAN hotspot infrastructure is proposed and investigated [62].

Optimal handoff control is very important for investigating the possibilities of handoff optimization by providing mobile terminals with additional information about the target system. An Always Best Connected (ABC) optimal channel assignment optimization is proposed based on multi-Particle Swarm Optimization (PSO) with optimum mutation [63]. A network-initiated handoff approach is presented to provide the QoS service continuity in UMTS/802.16e networks [64]. A novel common interworking sub layer is proposed at layer 2 on RNC, W-RNC and User Equipment (UE) to provide a seamless PS inter-RAT handoff between UMTS and WiMAX [65]. This IW sub-layer scheme focuses on eliminating packet loss and reducing handoff latency which are common problems for most inter-RAT handoff scenarios. In addition, this IW sub-layer scheme can eliminate false fast retransmit of TCP traffics which is usually caused by packet losses or out-of-order packet arrivals. A middleware architecture is proposed to support multimedia services across inter technology radio access networks in a secure and seamless manner [66]. A Vertical Handoff Translation Center Architecture has been proposed to improve the transmission which is guaranteed by QoS [67]. Thus, the quality of transmission cannot be reduced enormously even by the effect of vertical handoff between heterogeneous wireless networks. A multi-service load balancing mechanisms has been proposed in an overlay heterogeneous WiMAX/WLAN network through vertical handoff [68]. Two load balancing mechanisms are compared, which switch the elastic application with Maximum (MAX) and Minimum (MIN) remaining size respectively to WLAN. A new industrial design has been presented for the Wi-Fi/WiMAX vertical handoff [69]. The proposed vertical handoff is performed at the logical adaptation layer above the MAC layer. The results of the new algorithm shows less protocol converter time overhead, which can guarantee the QoS. The realization of the inter-working between these two standards is discussed and evaluated. The performance of a RSSI based VH algorithm is evaluated by computing the WLAN usage efficiency and deriving the required signal strength thresholds for handoff decisions that meet given target outage probabilities [70]. Based on impact of statistical fluctuations parameters, a soft algorithm has been proposed that exploits the statistical knowledge in order to reduce outage probability [71]. A solution for improving the QoS during vertical handoff between UMTS and WiMAX networks has been proposed for real time video applications. The performance analysis shows that the parameters, such as delay and throughput, are strongly dependent upon the speed of the mobile terminals, showing higher delays and bigger throughput gap as velocity increases. A vertical handoff decision algorithm has been proposed with Handoff Necessity Estimation 'HNE' method which determines the necessity of making a handoff to an available network [72]. It considered various parameters such as the AP power level, RSS samples, the radius of the network, the velocity of the Mobile Terminal (MT), the handoff latency, handoff failure and unnecessary handoff probability requirements for handoff decision. A UMTS-WiMAX internetworking architecture has been proposed based on MIH (IEEE 802.21) for UMTS and WiMAX heterogeneous network for seamless intersystem handoff [73]. The handoff procedure is presented based on the Media Independent Handoff Function (MIHF) which is guided by Media-Independent Information Service (MIIS) server [74]. A new architecture called Context Aware

Mobility Management System has been proposed for seamless handoff of users and services [75]. A handoff between WiMAX and Wi-Fi has been presented and exploited through an implementation in ns-2, introducing a simple, but effective, energy-saving approach. A handoff criteria based on combined receiving SINR from WLAN and WCDMA networks has been proposed, which provides the knowledge of the achievable bandwidth from both access networks [77]. The proposed approach has introduced increased handoff delay with excessive handoff and ping-pong effect. The performance impact of the handoff delay should be improved to minimize the probability of unnecessary handoffs. Increased connection breakdown probability without considering the RSS is observed in algorithm [78]. Based on quality of service parameters, mobility and location information, network access cost and the signaling load, a vertical handoff decision algorithm has been proposed for 4G wireless networks [53].

With load balance and connection management an algorithm is formulate with the objective of maximizing the expected total reward of a connection. The constraint of the problem is on the user's budget for the connection. A stationary randomized policy is obtained when the connection termination time is geometrically distributed. A vertical handoff decision algorithm has been developed that enables a wireless access network which not only balances the overall load among all attachment points. For more seamless integration of heterogeneous wireless networks, a route selection algorithm has been developed to forward data packets to the most appropriate attachment point in order to maximize the collective battery lifetime as well as maintain load balancing. VHDC selects the optimum BS/AP, based on load and battery power without considering the distance [79]. The Kalman filter is used to extract the signal strength using mean square estimation method. Local mean power estimator is used with window based method [80]. A vertical handoff decision algorithm based on Kalman estimation is proposed for WLAN cell to a Cellular Network (CN) cell handoff [81]. One of the most challenging problems for coordination is vertical handoff, which is the decision for a mobile node to change the point of attachment between different types of network. In vertical handoff, the velocity factor has a larger weight and imperative effect in handoff decision than in traditional horizontal handoffs [82].

A decision for vertical handoff may depend on several issues relating to the current network that the mobile node is already connected to and to the network that it is going to the handoff. Vertical handoff to a high power consuming network is not desirable, if the mobile terminal's battery is nearly exhausted or the battery's lifetime is relatively short. The cost of the different services to the user is a major issue for the choice of a network. For different networks, there would be different charging policy, therefore, in some situations the cost of a network should be taken into consideration while making handoff decisions. For some applications, confidentiality or integrity of the transmitted data can be critical. For this reason, a network with higher security level may be chosen over another one which would provide lower level of data security. Signal strength, which is normally used as a key deciding factor for horizontal handoff cannot be used in vertical handoff decision, due to the nature of coverage of heterogeneous network and different physical technique used by each technology [84].

As there are so many issues and challenges in vertical handoff analysis, the proposed approach has been presented for WLAN-WiMAX vertical handoff QoS support in next Chapter.

Chapter 3

WLAN-WiMAX Vertical Handoff

3.1 IEEE 802.21 Media Independent Handoff

IEEE 802.21 standard also known as Media Independent Handoff (MIH) provides quick handoff in a heterogeneous network [85]. This standard allows smooth and transparent service continuity, employing innovative IEEE 802.21 mobile devices. Three main elements of IEEE 802.21 standard are: MIH Frame work (MIHF), handoff enabling function and set of Service Access Points (SAP). The handoff in different access technologies is supported with MIHF. Fig. 3.1 depicts the main component of the MIHF.

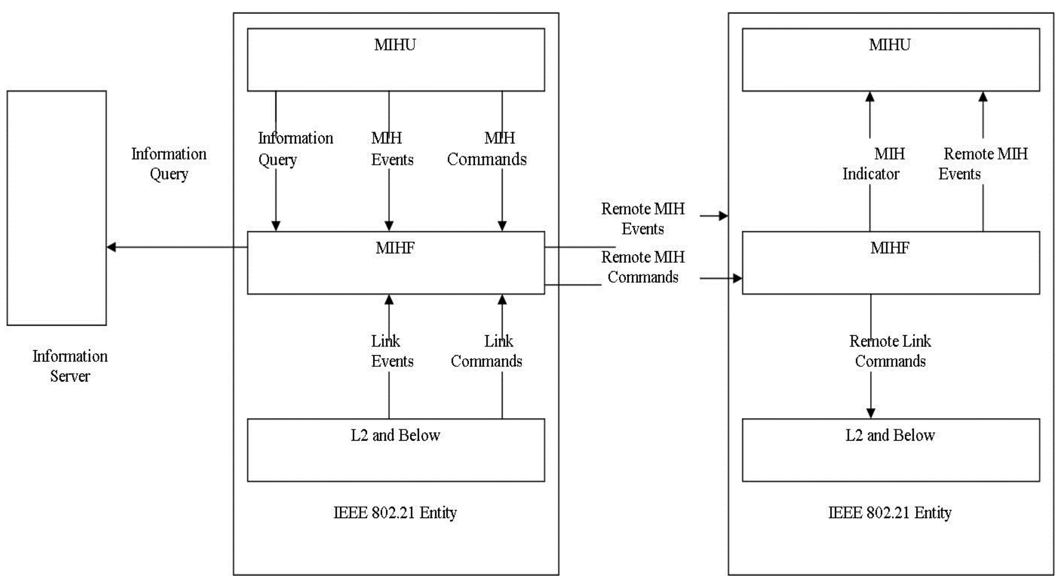

Fig: 3.1 MIHF Services [86]

MIHF is an extension of class based agent and therefore can send data to remote MIHF. The IEEE 802.21 local or remote L2 interfaces deliver events and triggers to the MIH Function (MIHF) layer called link events. These MIH events are made available to upper layers through the MIH Service AP (SAP). The MIH SAP enables MIHF to receive the link information. It is capable to assist handoff and also allows continues monitoring of available access conditions. The handoff management module uses these MIH events to discover available networks and to select the best access network.

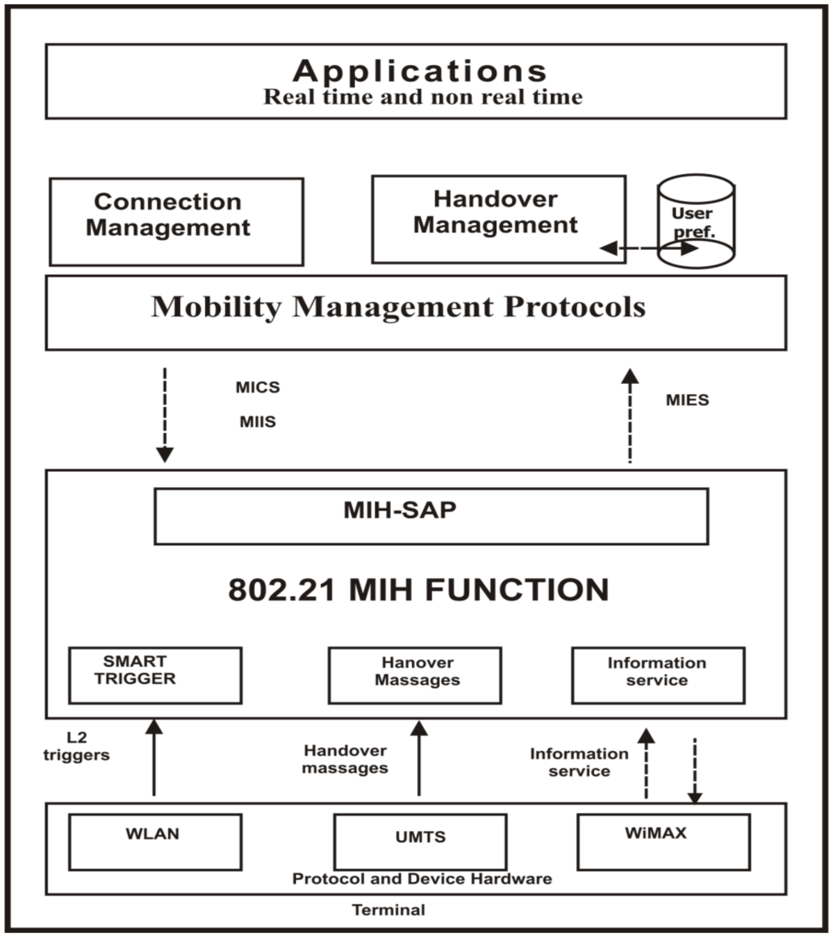

Fig: 3.2 MIH Frame work used for WLAN, WiMAX and UMTS

The three main services of MIHF are Media Independent Event Service (MIES), Media Independent Command Service (MICS) and Media Independent Information Service (MIIS). The MIES is used to provide information about link related events through the use of link triggers. The MIIS is used to collect information about the access networks that range from the location of the Point of Attachment ‘PoA’ to the capabilities. The technologies 803.2, 802.11, 802.15, 802.16 from IEEE standard and 3GPP & 3GPP2 based cellular technologies are supported in Link layer [86]. As shown in Fig. 3.2, IEEE 802.21 standard allows a user to move in a heterogeneous network environment with the help of technologies namely WLAN (802.11), WiMAX (802.16) and UMTS (3GPP).

3.2 Fuzzy Based Vertical Handoff Approach (FBVAH)

The combination of RSS and other factors like speed of mobile node, bandwidths etc. are able to improve the vertical handoff decision more appropriately [87-90]. In Fuzzy based approach, current RSS denoted as 'RSS' and predicted RSS denoted as 'PRSS', are the instant values at each sampled time. Velocity 'V' and available bandwidth 'B' are used as input parameters with RSS and PRSS for Fuzzy logic based Vertical handoff approach. For the fuzzy variables RSS and PRSS, let $R_{i\text{-}r1}$ be the minimal RSS value of the candidate in network i (i=RAT1 or RAT2), that is, $R_{RAT\text{-}r1=}$ P_{rRAT1} , $R_{W\text{-}r1=}P_{rRAT2}$; $R_{i\text{-}r2}$ to be the maximal RSS value that can be provided by any of radio access technology (RAT).

The Fuzzy set elements are represented in terms of membership degree of the set by the membership function *μ*. For example, *μA(x) is* used to represent the relationship between Fuzzy set A and element *x*. We have used centroid method as shown in (3.1) and (3.2)

$$\mu_O^l = \cap_{i=1}^{n} \mu_{o_i}^l(x_i) = \min[\, \mu_{o_1}^l(x_1) \ldots.. \mu_{o_i}^l(x_n) \qquad (3.1)$$

$$Y = \frac{\sum_{i=1}^{R} \mu_{o_i}^l \frac{i}{y}}{\sum_{i=1}^{R} \mu_{o_i}^l} \;, \qquad (3.2)$$

where i/y is the center of the output fuzzy membership value.

There are five fuzzy sets (Very Weak, Weak, Medium, Strong, and Very Strong) for RSS and PRSS. The fuzzy variable 'V' has five sets (Very Low, Low, Medium, High, and Very High) and fuzzy variable 'B' has three fuzzy sets (Low, Medium and High).

The membership function value ranges between 0 and 1 in general, Figures 3.3, 3.4 and 3.5 show membership functions for the RSS, velocity and available bandwidth from WLAN to WiMAX and from WiMAX to WLAN.

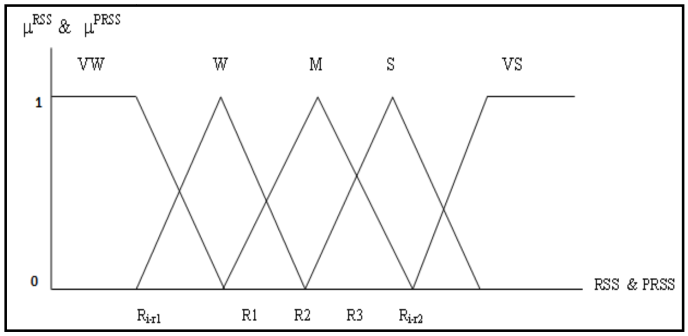

Fig: 3.3 Membership Function for RSS and PRSS

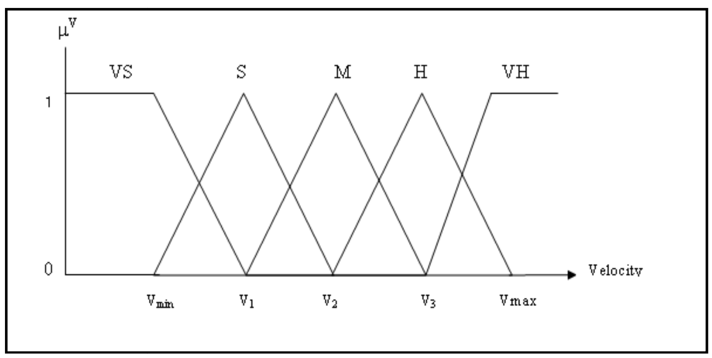

Fig: 3.4 Membership Function for Velocity

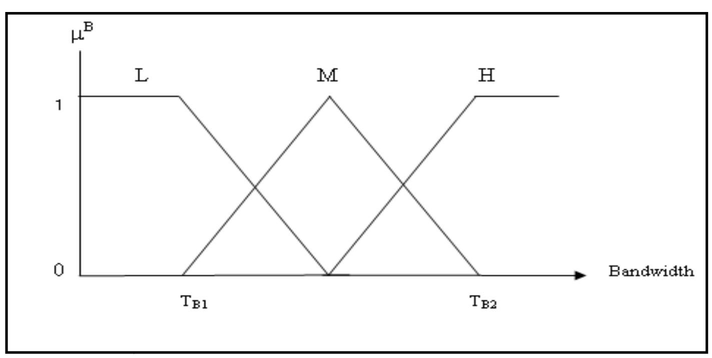

Fig: 3.5 Membership Function for Bandwidth

The membership function presentation of the RSS fuzzy variable [91] is given as:

$$\text{RSS} = \{\mu_{i-VW}^{RSS}, \mu_{i-W}^{RSS}, \mu_{i-M}^{RSS}, \mu_{i-S}^{RSS}, \mu_{i-VS}^{RSS}\} \tag{3.3}$$

Here *i* is used to represent the type of radio access technology and it is considered 1 for WLAN and 2 for WiMAX. The notation 'VW', 'W', 'M', 'S' and 'VS' are used to represent very weak, weak, medium, strong, and very strong RSS respectively. The membership function of the PRSS is given as:

$$\text{PRSS} = \{\mu_{i-VW}^{PRSS}, \mu_{i-W}^{PRSS}, \mu_{i-M}^{PRSS}, \mu_{i-S}^{PRSS}, \mu_{i-VS}^{PRSS}\}, \tag{3.4}$$

where notation 'VW', 'W', 'M', 'S' and 'VS' are used to represent very weak, weak, medium, strong, and very strong signal strength for PRSS respectively.

The membership function of velocity is given as

$$V = \{\mu_{i-VL}^{V}, \mu_{i-L}^{V}, \mu_{i-M}^{V}, \mu_{i-H}^{V}, \mu_{i-VH}^{V}\}, \tag{3.5}$$

where notation 'VL', 'L', 'M', 'H' and 'VH' are used to represent velocity range as very low, low, medium, high and very high respectively.

The bandwidth membership function is given as:

$$B = \{\mu_{i-L}^{B}, \mu_{i-M}^{B}, \mu_{i-H}^{B},\}, \tag{3.6}$$

where 'L', 'M' and 'H' are used to represent the bandwidth as low, medium and high respectively.

The normalization index (M) for RSS and PRSS is given as:

$$\left.\begin{aligned} M_i^{RSS} &= \left[M_{i-VW}^{RSS}, M_{i-W}^{RSS}, M_{i-M}^{RSS}, M_{i-S}^{RSS}, M_{i-VS}^{RSS}\right] \\ M_i^{PRSS} &= \left[M_{i-VW}^{PRSS}, M_{i-W}^{PRSS}, M_{i-M}^{PRSS}, M_{i-S}^{PRSS}, M_{i-VS}^{PRSS}\right] \end{aligned}\right\} \tag{3.7}$$

For i= 1 and 2 (WLAN and WiMAX respectively), the normalization index is computed for RSS and PRSS. The normalization values are computed as product of normalization index and membership function value of input variable [94]. The normalization value for RSS is given as:

$$NV_i^{RSS} = [M_{i-VW}^{RSS}, M_{i-W}^{RSS}, M_{i-M}^{RSS}, M_{i-S}^{RSS}, M_{i-VS}^{RSS}] \times [\mu_{i-VW}^{RSS}, \mu_{i-W}^{RSS}, \mu_{i-M}^{RSS}, \mu_{i-S}^{RSS}, \mu_{i-VS}^{RSS}], \tag{3.8}$$

where for i= 1 (WLAN) or 2(WiMAX), the 'VW', 'W', 'M', 'S' and 'VS' are used to denote the normalization index and membership function for RSS as very weak, weak, medium, strong and very strong respectively.

The normalization index for the PRSS is as shown below:

$$NV_i^{PRSS}=[M_{i-VW}^{PRSS}, M_{i-W}^{PRSS}, M_{i-M}^{PRSS}, M_{i-S}^{PRSS}, M_{i-VS}^{PRSS}]\times[\mu_{i-VW}^{PRSS}, \mu_{i-W}^{PRSS}, \mu_{i-M}^{PRSS}, \mu_{i-S}^{PRSS}, \mu_{i-VS}^{PRSS}], \quad (3.9)$$

where i= 1 (for WLAN) or 2(for WiMAX), the normalization index and membership function for PRSS are denoted as VW, W, M, S and VS, which represents the PRSS as very weak, weak, medium, strong and very strong respectively.

The normalization index for the input parameter velocity is given as

$$NV_i^{V}=[M_{i-VL}^{V}, M_{i-L}^{V}, M_{i-M}^{V}, M_{i-H}^{V}, M_{i-VH}^{V}]\times[\mu_{i-VL}^{V}, \mu_{i-L}^{V}, \mu_{i-M}^{V}, \mu_{i-H}^{V}, \mu_{i-VH}^{V}] \quad (3.10)$$

Here VL, L, M, H and VH is used to represent velocity range as very low, low, medium, high, very high respectively. The normalization index for the bandwidth is given as

$$NV_i^{B}=[M_{i-L}^{B}, M_{i-M}^{B}, M_{i-H}^{B}]\times[\mu_{i-L}^{B}, \mu_{i-M}^{B}, \mu_{i-H}^{B}] \quad (3.11)$$

Based on normalization values, the performance reward function value is given as

$$PRV_i= [\omega_1, \omega_2, \omega_3, \omega_4] \times [NV_i^{RSS}, NV_i^{PRSS}, NV_i^{V}, NV_i^{B}], \quad (3.12)$$

where ω1, ω_2, ω_3 and ω_4 are the weight factors assigned to RSS, PRSS, V and B respectively, and $\omega_1+ \omega_{2+} \omega_3+ \omega_4 =1$. Here values of ω_1, ω_2, ω_3, and ω_4 are considered 0.4, 0.3, 0.2 and 0.1 respectively. The performance reward function for two different RATS is computed. The handoff execution becomes necessary, if the following condition is satisfied.

If $PRV_{RAT1} > PRV_{RAT2}$ then handoff to RAT_1 (WLAN), else stay in RAT_2(WiMAX))

Else If $PRV_{RAT2} > PRV_{RAT1}$ then handoff to RAT_2 (WiMAX), else stay in RAT_1 (WLAN).

The fuzzy rules based on input parameters are given in Table 3.1.

Table 3.1 The Fuzzy Rules

Rule	If Velocity (V)	If BW (B)	AND RSS	THEN Vertical Handoff decision (WiMAX to WLAN)	THEN Vertical Handoff decision (WLAN to WiMAX)
R1	Very Slow	Low	Very Weak	Negative High	Positive Low
R2	Slow	Low	Very Weak	Negative High	Positive Low
R3	Medium	Low	Very Weak	Negative High	Positive Low
R4	High	Low	Weak	Negative High	Negative High
R5	Very High	Low	Weak	Negative High	Negative High
R6	Very Slow	Low	Weak	Negative High	Negative High
R7	Slow	Low	Medium	Positive Low	Positive Medium
R8	Medium	Low	Medium	Positive Low	Positive Medium
R9	High	Low	Medium	Positive Low	Positive Medium
R10	Very High	Low	Strong	Positive Medium	Negative low
R11	Very Slow	Low	Strong	Positive Medium	Negative low
R12	Slow	Low	Strong	Positive Medium	Negative low
R13	Medium	Low	Very Strong	Positive Medium	Positive low
R14	High	Low	Very Strong	Positive Medium	Positive low
R15	Very High	Low	Very Strong	Positive Medium	Positive low
R16	Very Slow	Low	Very Weak	Negative High	Negative High
R17	Slow	Low	Very Weak	Negative High	Negative High
R18	Medium	Low	Very Weak	Negative High	Negative High
R19	High	Low	Weak	Negative High	Negative High

R20	Very High	Low	Weak	Negative High	Negative High
R21	Very Slow	Low	Weak	Negative High	Negative High
R22	Slow	Low	Medium	Negative Medium	Positive Low
R23	Medium	Low	Medium	Negative Medium	Positive Low
R24	High	Low	Medium	Negative Medium	Positive Low
R25	Very High	Low	Strong	Negative Low	Positive Medium
R26	Very Slow	Medium	Strong	Negative Low	Positive Medium
R27	Slow	Medium	Strong	Negative Low	Positive Medium
R28	Medium	Medium	Very Strong	Negative Low	Positive High
R29	High	Medium	Very Strong	Negative Low	Positive High
R30	Very High	Medium	Very Strong	Negative Low	Positive High
R31	Very Slow	Medium	Very Weak	Negative High	Negative High
R32	Slow	Medium	Very Weak	Negative High	Negative High
R33	Medium	Medium	Very Weak	Negative High	Negative High
R34	High	Medium	Weak	Negative High	Negative High
R35	Very High	Medium	Weak	Negative High	Negative High
R36	Very Slow	Medium	Weak	Negative High	Negative High
R37	Slow	Medium	Medium	Zero	Zero
R38	Medium	Medium	Medium	Zero	Zero
R39	High	Medium	Medium	Zero	Zero
R40	Very High	Medium	Strong	Positive Medium	Negative Low
R41	Very Slow	Medium	Strong	Positive Medium	Negative Low
R42	Slow	Medium	Strong	Positive Medium	Negative Low
R43	Medium	Medium	Very Strong	Positive High	Positive Low
R44	High	Medium	Very Strong	Positive High	Positive Low
R45	Very High	Medium	Very	Positive High	Positive Low

			Strong		
R46	Very Slow	Medium	Very Weak	Negative Low	Positive High
R47	Slow	Medium	Very Weak	Negative Low	Positive High
R48	Medium	Medium	Very Weak	Negative Low	Positive High
R49	High	Medium	Weak	Negative Low	Positive Medium
R50	Very High	Medium	Weak	Negative Low	Positive Medium
R51	Very Slow	High	Weak	Negative Low	Positive Medium
R52	Slow	High	Medium	Positive Low	Positive Low
R53	Medium	High	Medium	Positive Low	Positive Low
R54	High	High	Medium	Positive Low	Positive Low
R55	Very High	High	Strong	Positive Medium	Negative Low
R56	Very Slow	High	Strong	Positive Medium	Negative Low
R57	Slow	High	Strong	Positive Medium	Negative Low
R58	Medium	High	Very Strong	Positive High	Negative Medium
R59	High	High	Very Strong	Positive High	Negative Medium
R60	Very High	High	Very Strong	Positive High	Negative Medium
R61	Very Slow	High	Very Weak	Negative Low	Positive High
R62	Slow	High	Very Weak	Negative Low	Positive High
R63	Medium	High	Very Weak	Negative Low	Positive High
R64	High	High	Weak	Negative Low	Positive Medium
R65	Very High	High	Weak	Negative Low	Positive Medium
R66	Very Slow	High	Weak	Negative Low	Positive Medium
R67	Slow	High	Medium	Positive Low	Negative Low
R68	Medium	High	Medium	Positive Low	Negative Low
R69	High	High	Medium	Positive Low	Negative Low
R70	Very High	High	Strong	Positive Medium	Zero

R71	Very Slow	High	Strong	Positive Medium	Zero
R72	Slow	High	Strong	Positive Medium	Zero
R73	Medium	High	Very Strong	Positive High	Negative Medium
R74	High	High	Very Strong	Positive High	Negative Medium
R75	Very High	High	Very Strong	Positive High	Negative Medium

As shown in Fig. 3.6, the fuzzy output membership function is considered having seven different ranges.

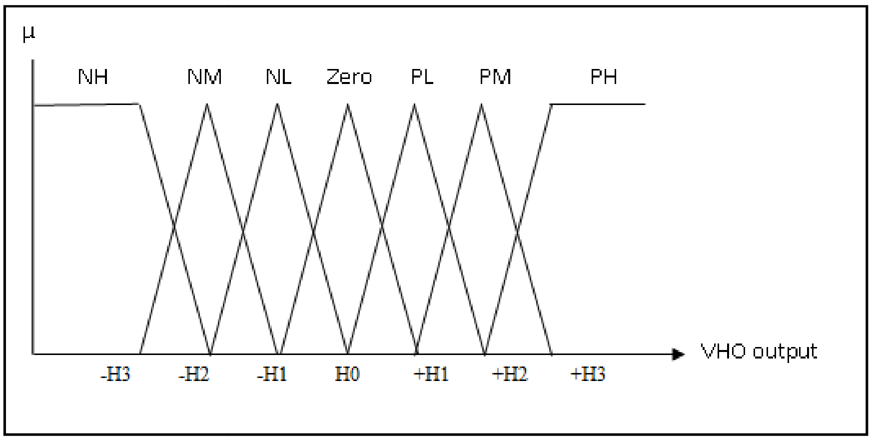

Fig: 3.6 Membership Function for VHO Decision

The notation NH, NM, NL, Zero, PL, PM and PH is used to represent negative high, negative medium, negative low, zero, positive low, positive medium and positive high respectively.

We have converted the output fuzzy membership value obtained by the fuzzy inference engine into a crisp value to use it as an actual control variable. This process is known as defuzzification.

For crisp value calculation, we have used the formula

$$W(A) = \frac{1}{6}(a + 4b + c) , \quad (3.13)$$

where $A = (a, b, c)$ represents the Triangular Fuzzy Number (TFN).

The crisp values for input parameters RSS and PRSS, velocity and bandwidth are given in Table 3.2, 3.3 and 3.4 respectively and for output parameter is given in Table 3.4.

Table 3.2: TFNs and their corresponding crisp values for RSS and PRSS

Linguistic variables	Triangular Fuzzy Numbers (TFNs)	Crisp Value
Very Weak	(0.0,0.1,0.2)	0.100
Weak	(0.1,0.2,0.4)	0.216
Medium	(0.2,0.4,0.6)	0.400
Strong	(0.4,0.6,0.8)	0.600
Very Strong	(0.6,0.8,1.0)	0.800

Table 3.3: TFNs and their corresponding crisp values for Velocity

Linguistic variables	Triangular Fuzzy Numbers (TFNs)	Crisp Value
Very Low	(0.0,0.1,0.3)	0.116
Low	(0.1,0.3,0.5)	0.300
Medium	(0.3,0.5,,0.7)	0.500
High	(0.5,0.7,0.9)	0.700
Very High	(0.7,0.9,1.0)	0.833

Table 3.4: TFNs and their corresponding crisp values for Bandwidth

Linguistic variables	Triangular Fuzzy Numbers (TFNs)	Crisp Value
Low	(0.0,0.3,0.5)	0.283
Medium	(0.3,0.5,0.7)	0.500
High	(0.5,0.7,1.0)	0.716

Table 3.5: TFNs and their corresponding crisp values for VHO Decision

Linguistic variables	Triangular Fuzzy Numbers (TFNs)	Crisp Value
Negative High	(0.0,0.2,0.3)	0.183
Negative Medium	(0.2,0.3,0.4)	0.300
Negative Low	(0.3,0.4,0.5)	0.400
Zero	(0.4,0.5,0.6)	0.500
Positive Low	(0.5,0.6,0.7)	0.600
Positive Medium	(0.6,0.7,0.8)	0.700
Positive High	(0.7,0.8,1.0)	0.816

The fuzzy rules (Table 3.1) have been implemented in fuzzy inference engine as shown in Fig. 3.7.

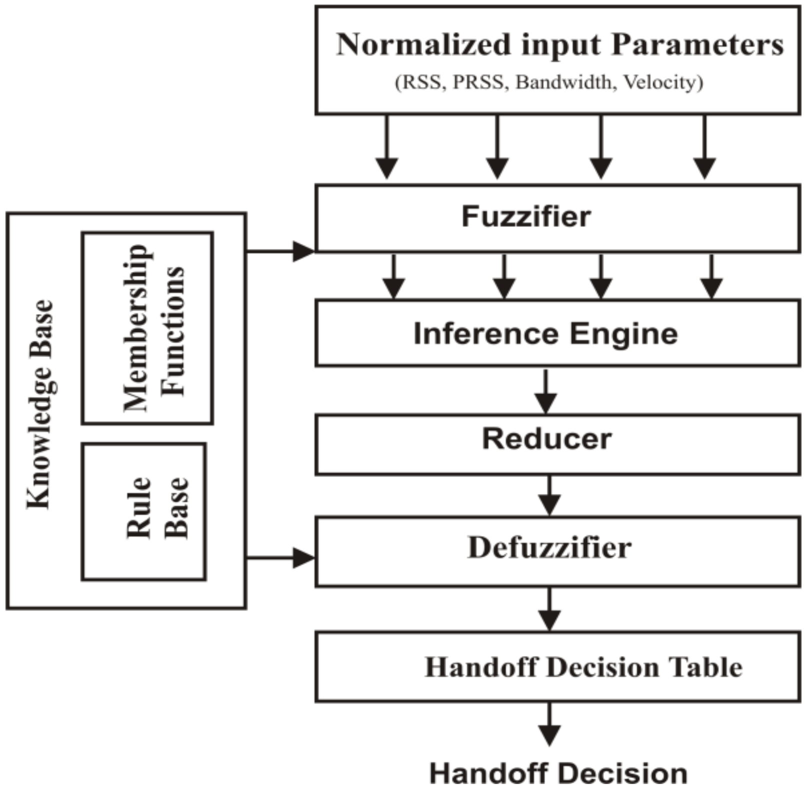

Fig: 3.7: Fuzzy Logic Controller Block Diagram

The fuzzy logic controller has different parts as input parameters in which the instant values of parameters are received [95]. These parameters are fuzzified and then compared with the rule already set in rule base. After defuzzification, the handoff selection is done based on output parameters function [96]. Based on input parameters, fuzzification, defuzzification rule base comparison in fuzzy logic controller, the Fuzzy Based Vertical Handoff Approach (FBVAH) is implemented for WLAN-WiMAX handoff scenario. In next section the proposed swarm based handoff approach is discussed.

3.3 Proposed Swarm Based Vertical Handoff Approach (SBVAH)

In present research work the handoff triggering condition is generally based on Received Signal Strength Indicator (RSSI) only. The excess load and degrading in QoS at base station raises the requirement of horizontal or vertical handoff triggering. The route discovery is performed by broadcasting the repeat request messages in case of adhoc networks, which is traditional method that increases the delay and overhead. Swarm intelligence is referred as complex behavior that arise from very simple individual behaviors and interactions, which is often observed in nature, especially among social insects such as ants [63]. Forward Ant (FA) is an agent which establishes link to the source node. In contrast, a Backward Ant (BA) establishes the link to the destination node. The forward ants are used to collect the information of traffic to move from one node to another. The backward ants follow the paths of forward ants in the opposite direction. During the backward routing, each node’s information is updated in routing table with additional table containing the statistics about the traffic. The Ant colony based Routing Algorithm (ARA) is suitable for mobile node in heterogeneous network environment for routing purpose [97]. ARA is a swarm intelligence technique; it uses ant colony meta heuristics [98]. There are three main phases of ARA, discovery of route, maintenance of route and failure handling of route. In route discovery phase, with FA and BS new links or routes are discovered. ARA is able to select best quality path by calculating the highest pheromone value from the available multiple paths.

The input parameters considered are received signal strength, cost of the radio access technology and speed of the mobile terminal. The QoS parameters considered are delay and bit rate.

The Swarm Intelligence (SI) approach is proposed approach for route selection in order to improve the performance and routing decisions. Swarm Intelligence-based techniques can be used in a number of applications [99].

Small packets in form of FA and BA as shown in Fig. 3.8 (a) and 3.8 (b) are used for routing purpose to collect information.

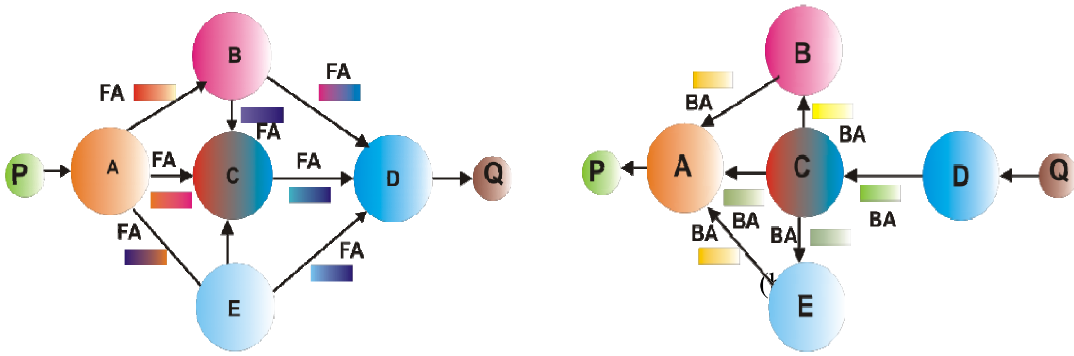

Fig: 3.8 (a) Forward Ant Movement and (b) Backward Ant Movement

The Swarm Based Vertical Handoff Algorithm (SBVAH) is based on information deposited as a meaningful pheromone in table. In this algorithm actual value pheromones of neighboring serving node are deposited in Table 3.6 and 3.7.

Table 3.6 Forward Path

Path	Next Node	Path Weightage
F1	<A,B,D>	0.584
F2	<A,B,C,D>	0.346
F3	<A,C,D>	0.773
F4	<A,E,C,D>	0.666
F5	<A,E,D>	0.827

Table 3.7 Backward Path

Path	Next Node	Path Weightage
B1	<D,C,A>	0.852
B2	<D,C,B,A>	0.773
B3	<D,C,E,A>	0.758

These entries entered in table are useful to measure the goodness or usefulness of selecting the neighboring station or access point. These information or entries are termed pheromone variables. In search process, information is stored in table. The ants calculate the quality of path from continually updated table. In heterogeneous network swarm discovery phase searches the progresses and then pheromones are deposited and evaporated in table based on the path traversed by the ants.

The ants use the routing tables to select which path to their destination they sample. Once the vertical handoff is initiated, the ant based route discovery will be started. The creation of new routes requires the use of a Forward Ant (FA) and Backward Ant (BA). The FA visits each BS or AP and collects bandwidth, battery lifetime and distance. When the destination AP or BS is reached, the BA inherits the FA and once again collects bandwidth, battery lifetime and distance parameters of the visited AP or BS.

During the search, the higher the pheromone value in table, the greater is the probability of selecting the corresponding element value.

This also shows that there exist multiple paths between the source and the destination. During the backward travel, information for each visited node is updated based on the trip time. With generation of link failure massage, the best link estimation factor for new path is calculated. Each forward ant searches for the destination by selecting the best neighboring network according to the Link Probability Distribution function [100] as given below:

$$A_K(P_i, Q_O) = \begin{Bmatrix} \dfrac{[\ \alpha(P_i, Q_O)^{\zeta},\ \ \beta(P_i, Q_O)\ ]^{\sigma}}{\Sigma_{M_i = M_R}\ [\ \alpha(P_i, Q_O)^{\zeta},\ \ \beta(P_i, Q_O)\ ]^{\sigma}} & \\ 0, otherwise & if\ k \epsilon L^{M_i} \end{Bmatrix} \quad , \tag{3.14}$$

where $A_k\ (P_i\ ,Q_o)$ is the probability used for forward ant k to move from node P to node Q, $\alpha(P_i, Q_O)$ represent pheromone (network serving condition) value, and $\beta(P_i, Q_O)$ is used to represent bandwidth heuristic value. M_R represents the receiver node. L^{M_i}

represents the routing table for node M_i. Also ζ and σ are the relative weight of the pheromone and heuristic value respectively.

In the next route exploration, the link probability distribution of each intermediate node will be updated according to the pheromone concentration. Using several iterations, each node will be able to know which neighbors are the best. The swarm based algorithm is a technique to find the next best suitable network from source to destination. The selection algorithm method is as described:

1. Start the searching for best network node.
2. Set the weight for each entity travelled from P to Q node.
3. Run the shortest path algorithm from P until the destination Q is reached.
4. The result is the total number of paths for a given source to all destinations.

To provide flexibility in selecting an appropriate route, weights are assigned to select best access network over the other. The total cost for route is best route path is calculated as in eq. (3.15)

$$\text{Total Cost} = w_1 c_1 + w_2 c_2 \quad , \tag{3.15}$$

where, w_1 and w_2 are weights assigned to bandwidth and shortest path cost factor respectively with condition of $w_1 + w_2 = 1$. A higher weight w_2 should be assigned for a delay sensitive real time application, such as voice in proposed swarm based approach with the minimum hop count. The notation c_1 is used for cost factor for bandwidth of network available and c_2 is cost factor for shortest path found i.e. minimum number of hops.

The MN is located in the access networks, and can provide vertical handoff decision function for a region covering one or multiple access points or Base Stations (BS). The handoff trigger is based on the Received Signal Strength Indicator (RSSI) and Load.

Whenever, the total load of the AP or BS exceeds its available bandwidth or the RSSI of a MN falls below a threshold value (in case of AP) or the RSSI from one or more APs exceed a threshold (in case of BS), the handoff process is initiated. The vertical handoff decision SBVAH is performed based on the type of application running on the MN. To select the target network, the network with high bandwidth is chosen for inelastic (real time) applications. For elastic applications, the network with good battery lifetime and distance parameters are chosen.

3.4 Simulation Model

The performance evaluation has been performed through simulation using ns-2 with NIST model add-ons and extended appropriately to MIH procedure [85]. We have evaluated the proposed swarm based approach SBVAH algorithm and FBVAH algorithm by setting up a approach considering two wireless technologies Wi-Fi (or WLAN) and WiMAX. Simulation scenario is a square area of 1000 meter square, in which WiMAX cell is overlaid by two WLAN cell networks as shown in Fig. 3.9. The 802.21 protocol directives are managed by each element of the network.

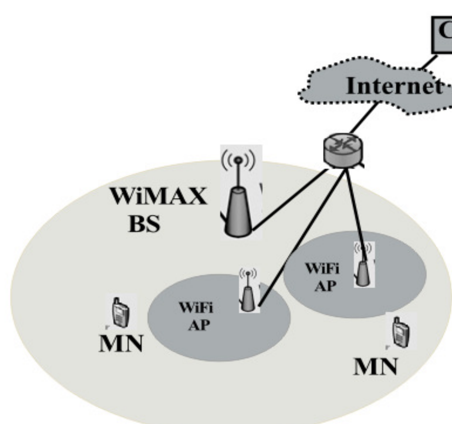

Fig: 3.9 Integrated architecture for WLAN / WiMAX Handoff

The MN is initially associated with WiMAX and it is assumed that Global Positioning System 'GPS' functionality is available. This enables the MN to retrieve information about neighbor networks in its vicinity (r meters) and based on its exact location. The simulation parameters used for scenario are given in Table 3.8.

Table 3.8: Simulation Settings and Parameters

Area Size	1000 mts X 1000 mts
Mac	802.16 and 802.11
Clients	20
Traffic Source	CBR and Video
No. of CBR Flows	4
No. of Video Flows	2
No. of WiMAX BSs	1
No. of WLAN APs	2

3.5 Results and Discussions

3.5.1 Result Analysis Based on Load

Varying load with respect to packet size, the QoS parameters packet delivery ratio, end to end delay, jitter and throughput have been observed and analyzed for the proposed swarm based vertical handoff approach.

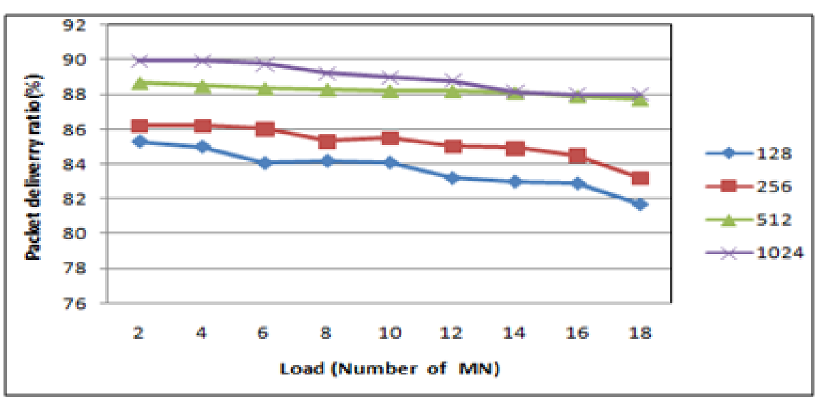

Fig: 3.10 Packet Delivery Ratio with Varying Number of MN and Packet Size

Packet Delivery Ratio has been shown in Fig. 3.10. It has been observed that as load is increasing, the packet delivery ratio is decreasing with respect to variation in packet size. For packet size 128, the highest packet delivery ratio has been observed as 85% and lowest as 81.9% at load 2 and 18 respectively. The packet delivery ratio has been observed better in 256 packet size as compared to packet size 128 with varying load. Further as packet size is increasing from 128 to 1024 the packet delivery ratio is also increasing, which gives maximum data carrying capacity to network.

Packet delivery ratio is inversely proportional to network load parameter. As long as number of nodes increases, successful delivery of packets in terms of packet delivery ratio decreases. The maximum packet delivery ratio in 1024 is observed 90% and 88%, at load 2 and 18 respectively.

It has been observed from the Fig. 3.11, that delay response goes on increasing with respect to increase in load, for various packet sizes 128, 256, 512, 1024. The Delay response has been observed maximum (undesirable) at packet size 128 with increasing load. Delay response has been observed better for packet variation from 128 to 1024.

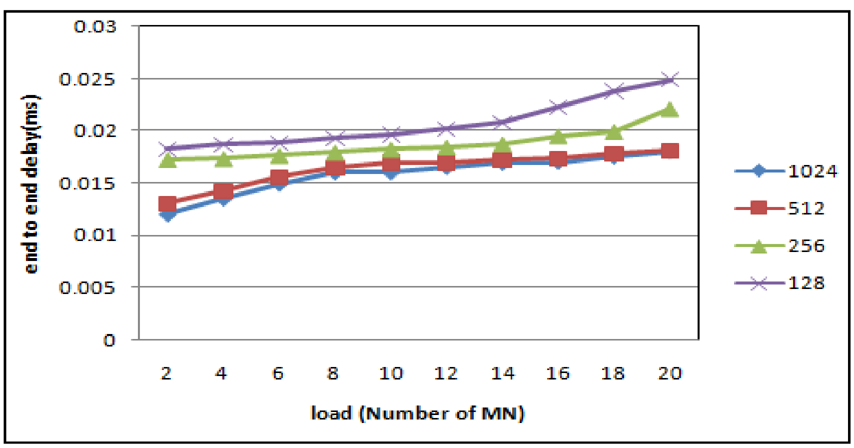

Fig: 3.11 End to End Delay with Varying Number of MN and Packet Size

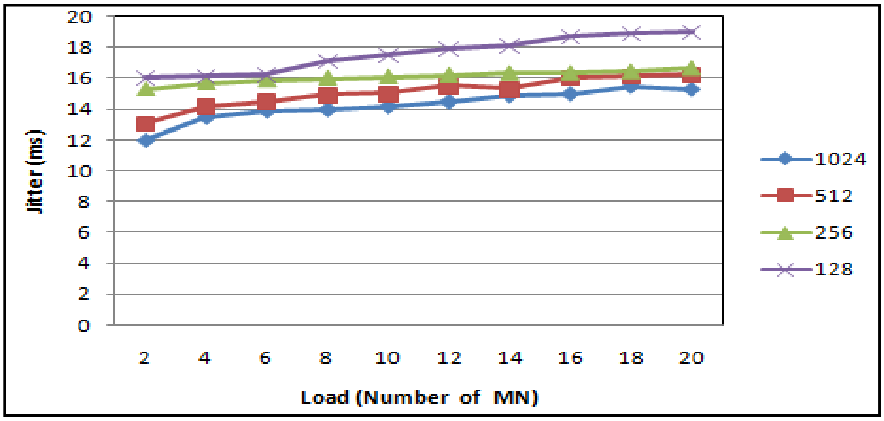

Fig: 3.12 Jitter Responses with Varying Number of MN and Packet Size

The jitter response is depicted and analyzed in Fig. 3.12 with respect to load. At load 2, it has been observed 12 ms and 16 ms, for packet size 1024 and 128 respectively. With variation in packet size from 128 to 1024 jitter response gets improved.

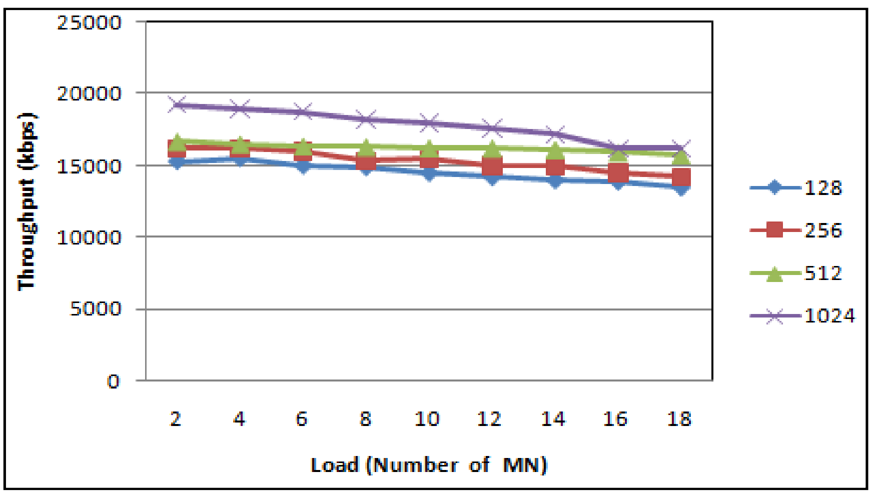

Fig: 3.13 Throughput Responses with Varying Number of MN and Packet Size

As shown in Fig. 3.13 it has been observed that throughput is decreased with increase in load for packet size variation from 128 to 1024. The throughput response has been observed better in packet size 1024 as compared to minimum with a packet size 128.

3.5.2 Result Analysis Based on MN Speed

The scope of scenario given in Table 3.9 is to measure system performance in terms of packet delivery ratio, jitter response, end to end delay and throughput for different speed of MN ranging from 2 to 20 mps. It is important to mention that packet delivery is defined as the ratio of successful packets delivered to the number of packets transmitted.

Table 3.9: Simulation Settings and Parameters

Area Size	1000 mts X 1000 mts
Mac	802.16 and 802.11
MN speed	1 to 20 mps
No. of CBR Flows	4
No. of Video Flows	2
No. of WiMAX BSs	1
No. of WLAN APs	1

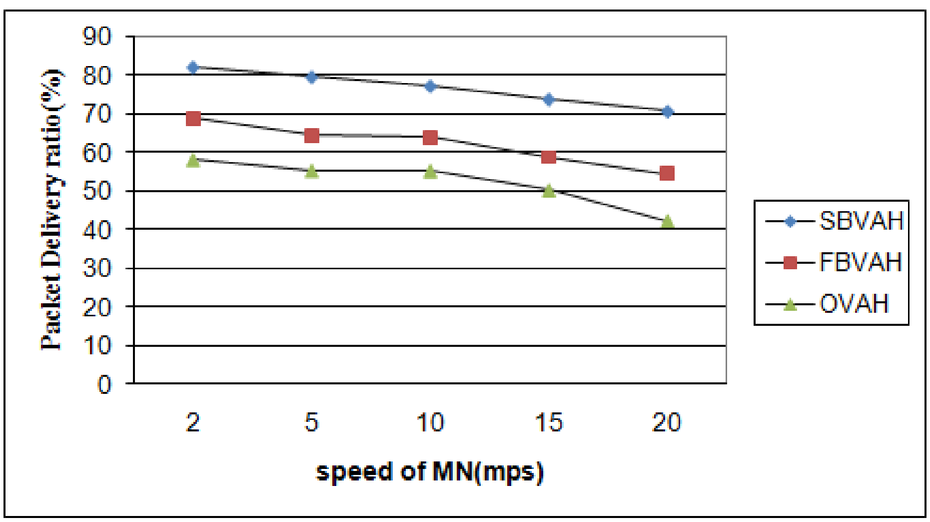

Fig: 3.14 Packet Delivery Ratio with Increasing MN Speed

It is observed from the Fig. 3.14 that as speed increases the packet delivery ratio decreases. In this scenario the results for proposed SBVAH approach have been compared with fuzzy based approach (FBVAH) and the Ordinary RSSI based approach (OVAH). The packet delivery ratio has been observed better and improved for proposed SBVAH for all values of MN speed as compared to FBVAH approach and OVAH approach.

As shown in Fig. 3.15, the lowest end to end delay of 0.8 sec, 1.2 sec and 1.9 sec for SBVAH, FBVAH and OVAH respectively at MN speed 2 mps has been observed. The delay parameter has been observed highest at 2.7 sec, 3.0 sec and 3.6 sec for SBVAH, FBVAH and OVAH respectively at MN speed 20 mps. The delay response has been observed better for proposed SBVAH approach as compared to FBVAH and OVAH.

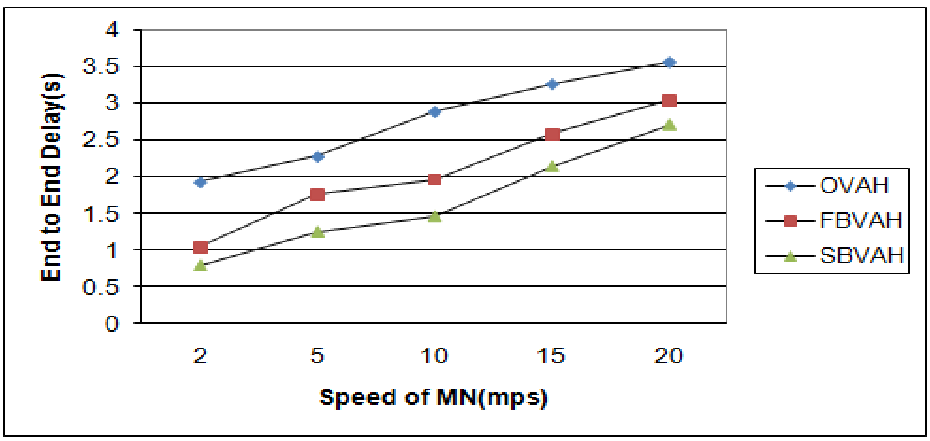

Fig: 3.15 End to End Delay with Increasing MN Speed

It has been observed from the Fig. 3.16 that the SBVAH is giving better results as compared to FBVAH and OVAH approach. Jitter has been observed increasing with respect to increase in MN speed. It has been observed better for proposed SBVAH approach for increasing MN speed as compared to FBVAH and OVAH approach.

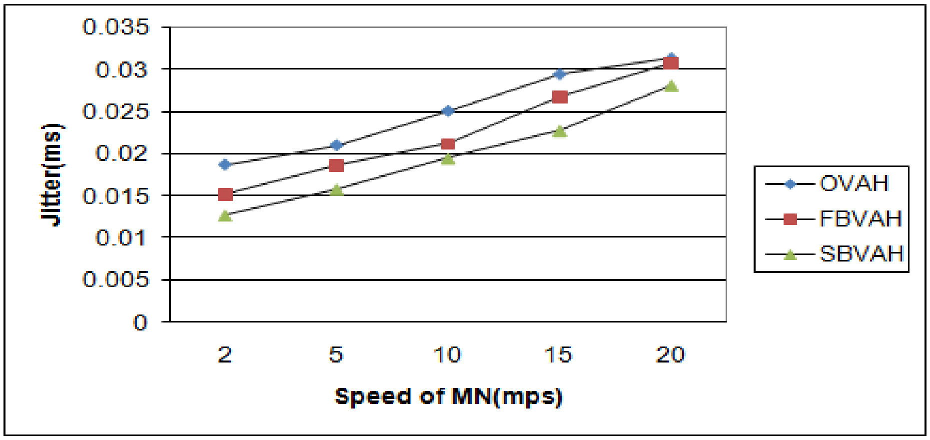

Fig: 3.16 Jitter Response with Increasing MN Speed

From Fig. 3.17, it has been observed that the throughput response goes on decreasing with respect to increase in MN speed. The results obtained for the proposed SBVAH has been found better and improved as compared to FBVAH and OVAH.

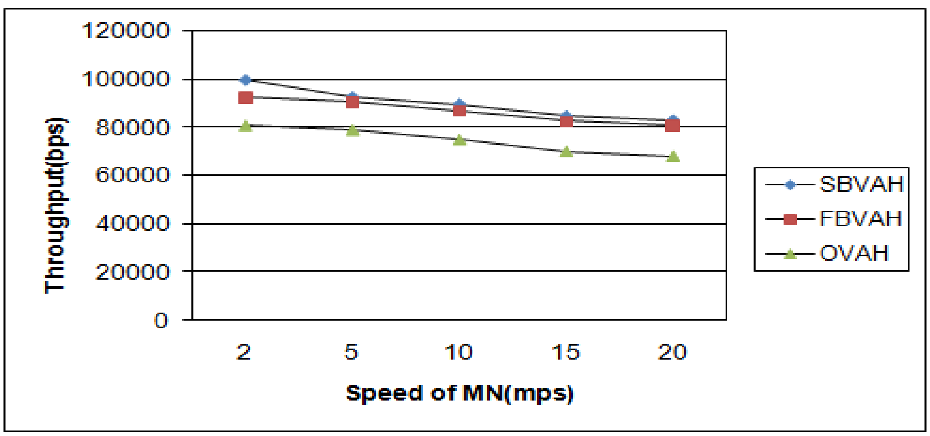

Fig: 3.17 Throughput Response with Increasing MN Speed

In this chapter, the vertical handoff scenario for WLAN-WiMAX has been presented. The proposed SBVAH approach has been compared with OVAH and FBVAH approach. The results obtained for the proposed approach SBVAH have been found better and consistent over FBVAH and OVAH. In next chapter, the vertical handoff for UMTS-WLAN has been presented.

Chapter 4

WLAN-UMTS Vertical Handoff

4.1 Data Rate Based Vertical Handoff (DR-VADH)

The instantaneous parameter data rate is beneficial for vertical handoff decision in UMTS and WLAN network [101]. Goodput is defined as the data rate delivered by network from source to destination per unit time [39]. The Signal to Interference Ratio '$S^{wlan}_{AP_{i,j}}$' as derived in [77], received by j^{th} user from i^{th} WLAN access point is given as:

$$S^{wlan}_{AP_{i,j}} = \frac{G_{AP_{i,j}} P_{AP_i}}{P_B + \sum_{\substack{k \in AP \\ k \neq j}} G_{AP_{k,j}} P_{AP_k}}, \qquad (4.1)$$

where P_{AP_i} : transmit power from i^{th} WLAN AP.

$G_{AP_i,j}$: Channel gain between j^{th} Mobile node user and i^{th} WLAN AP.

P_B : Back ground noise power at the terminal level.

The Signal to Interference Ratio '$S^{umts}_{BS_{i,j}}$' received by mobile user *'j'* from UMTS base station *'i'* is given as [77] in (4.2)

$$S^{umts}_{BS_{i,j}} = \frac{G_{BS_{i,j}} P_{BS_{i,j}}}{P_B + \sum_{k \epsilon BS} (G_{BS_{k,j}} P_{BS_k}) - (G_{BS_{i,j}} P_{BS_{i,j}})}, \qquad (4.2)$$

where $P_{BS_{ij}}$: Total transmitted power by UMTS base station BS_i to mobile node 'j'.

P_{BS_k} : Total Transmitted power of UMTS base station BS_k.

$G_{BS_{k,}}$: Channel gain between j^{th} Mobile node user and k^{th} UMTS base station.

Traditional handoff approach is based on RSS. Further improvement in QoS during handoff is achieved as considering data rate for WLAN and UMTS network. According to Shannon's capacity formula maximum data rate 'D_{AP}' from WLAN access point in terms of receiving SINR '$S_{AP_{i,j}}^{wlan}$' is given as:

$$D_{AP} = W_{AP} \log_2 \left[1 + \frac{S_{AP}^{wlan}}{\Gamma_{AP}}\right], \tag{4.3}$$

where W_{AP} career bandwidth of WLAN and Γ_{AP} is channel coding loss factor in WLAN. The maximum data rate 'D_{BS}' from UMTS base station in terms of receiving SINR '$S_{BS_{i,j}}^{umts}$' is given as:

$$D_{BS} = W_{BS} \log_2 \left[1 + \frac{S_{BS}^{umts}}{\Gamma_{BS}}\right], \tag{4.4}$$

where W_{BS} and Γ_{BS} are career bandwidth and channel coding loss factor in UMTS respectively. Since data rate of UMTS and WLAN network are different. Thus to compare the SINR of UMTS and WLAN, the SINR of source node is required to be converted into SINR of destination node. Assuming the data rate D_{AP} and D_{BS} are equal, we have obtained the relationship between the SINR of UMTS and WLAN, using (4.3) and (4.4) which is given as:

$$S_{BS}^{umts} = \Gamma_{BS} \left(\left(1 + \frac{S_{AP}^{wlan}}{\Gamma_{AP}}\right)^{\frac{W_{AP}}{W_{BS}}} - 1 \right) \tag{4.5}$$

The SINR of source node is compared with destination node as calculated in eq. (4.5). This also gives handoff triggering ability based on data rate. At time of mobile node connectivity and switching to different network, the data rate gain margin 'D_g' is deciding factor for handoff triggering. The data rates for WLAN and UMTS networks are compared. The down link handoff will be triggered from UMTS to WLAN, if the data rate at AP is greater than data rate at BS, and is given as:

$$D_{AP} - D_{BS} > D_g \tag{4.6}$$

The uplink handoff will be triggered from WLAN to UMTS:

$$D_{AP} - D_{BS} < D_g \tag{4.7}$$

With the use of eq. (4.6) and (4.7), the proper handoff decision can take place attaining higher throughputs and minimizing the number of handoff.

4.2 Proposed Smart Routing Based Vertical Handoff (SR-VADH)

For proposed SR-VADH algorithm we have considered radio access technologies namely WLAN and UMTS as shown in Fig. 4.1. As coverage range of UMTS is relatively larger as compared to WLAN, WLAN is configured as small cell with in UMTS. The set of WLAN access point's (AP) is represented as **X**, as given in (4.8)

$$\mathbf{X} = [AP_1, AP_2, AP_3, \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots, AP_k], \tag{4.8}$$

where *k* is total number of available WLAN access points.

In UMTS the total number of base stations is denoted as **Y** and is given in (4.9)

$$\mathbf{Y} = [BS_1, BS_2, BS_3, \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots, BS_l], \tag{4.9}$$

where *l* is total number of available UMTS base stations.

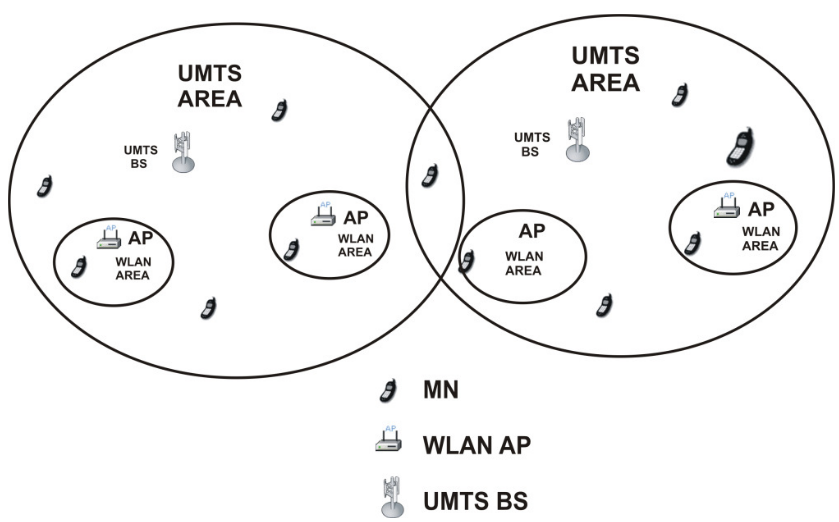

Fig: 4.1 Vertical Handoff Scenario for Wireless Network UMTS /WLAN

The notation '**M**' is used to represent the set all of mobile node (MN) available in overall coverage given as:

$$\mathbf{M} = [m_1, m_2, m_3, m_4, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots, m_j], \tag{4.10}$$

where j is total number of available mobile nodes in set M. It is assumed that MN will be connected with one of the available network UMTS or WLAN at any instant. The association of MN with available AP's of WLAN is given as:

$$AP_i \in \mathbf{X} \ (1 \leq i \leq k) \tag{4.11}$$

The load 'ρ_{AP}' in WLAN is given as:

$$\rho_{AP_i} = \sum_{j \in M} b_{ij} \ , \qquad \text{for } 1 \leq i \leq k \tag{4.12}$$

where b_{ij} is effective bandwidth received by j^{th} mobile node connected to i^{th} WLAN access point. The association of MN with available BS's of UMTS is given as:

$$BS_i \in \mathbf{Y} \ (1 \leq i \leq l) \tag{4.13}$$

The load in UMTS is given as:

$$\rho_{BS_i} = \sum_{j \in \mathbf{M}} b_{ij}^{u} \ , \qquad \text{for } 1 \leq i \leq l \tag{4.14}$$

Where b_{ij}^{u} is the effective bandwidth of j^{th} mobile node connected with i^{th} base station of UMTS. The relative signal strength is used to compare the signal strength of different radio access technology available at that instant of time [103].

The relative signal strength of UMTS 'S_{umts}' is given as:

$$S_{umts} = \frac{R_{umts}^{c} - R_{umts}^{ith}}{R_{umts}^{max} + R_{umts}^{ith}} \ , \tag{4.15}$$

where R_{umts}^{max} the maximum is transmitted received signal strength of UMTS and R_{umts}^{c} is the current received signal strength from UMTS, which is given as:

$$R_{umts}^{c} = R_{umts}^{max} - 10\eta \log (d_{umts}) \ , \tag{4.16}$$

Where η is path loss exponent and d_{umts} is separation between the mobile node and base station in meters.

R_{umts}^{ith} is the receiver threshold in UMTS is given as in (4.17)

$$R_{umts}^{ith} = R_{umts}^{max} - 10\eta \log(D_{umts}) \, , \qquad (4.17)$$

where D_{umts} is the reference distance for RSS measurement from UMTS BS.

Using (4.16) and (4.17), the relative signal strength of UMTS is given as in (4.18)

$$S_{umts} = 1 - \frac{\log(d_{umts})}{\log(D_{umts})} \qquad (4.18)$$

S_{umts} is calculated for all base stations, i.e. **Y** = 1, 2, 3,……, *l*.

The relative signal strength of WLAN is given as:

$$S_{WLAN} = \frac{R_{WLAN}^{C} - R_{WLAN}^{ith}}{R_{WLAN}^{C} + R_{WLAN}^{ith}} \, , \qquad (4.19)$$

where R_{WLAN}^{max} is the maximum transmitted signal strength of WLAN.

R_{WLAN}^{c} is the current received signal strength of WLAN as given in (4.20).

$$R_{WLAN}^{c} = R_{WLAN}^{max} - 10\eta \log(d_{WLAN}) \, , \qquad (4.20)$$

where η is path loss exponent and d_{WLAN} represents separation between the mobile node and access point in meters.

R_{WLAN}^{ith} is the received threshold value in WLAN, which is given in (4.21).

$$R_{WLAN}^{ith} = R_{WLAN}^{max} - 10\eta \log(D_{WLAN}) \, , \qquad (4.21)$$

where D_{WLAN} is the reference distance for RSS measurement from WLAN access point.

The relative signal strength of WLAN is given by (4.22)

$$S_{WLAN} = 1 - \frac{\log(d_{WLAN})}{\log(D_{WLAN})} \qquad (4.22)$$

S_{WLAN} is calculated for all access points, i.e. for **X**= 1, 2, 3,…………, k.

There exist two conditions, one for horizontal handoff and second for vertical handoff. The horizontal handoff occurs in WLAN if following condition as given in (4.23) is satisfied.

$$S_{WLAN,X_1} > S_{WLAN,X_2} \qquad (4.23)$$

Compare the S_{WLAN} for all available WLAN access points i.e. $AP_i \in \boldsymbol{X}$ $(1 \leq i \leq k)$.

The horizontal handoff occurs in UMTS if condition given by (4.24) is satisfied.

$$S_{UMTS,Y_1} > S_{UMTS,Y_2} \tag{4.24}$$

Compare the S_{UMTS} for all available UMTS base stations i.e. $BS_i \in Y\ (1 \leq i \leq l)$.

The vertical handoff is executed from WLAN to UMTS, if following condition is satisfied as given in (4.25)

$$S_{UMTS,l} > S_{WLAN,k} \tag{4.25}$$

The vertical handoff from UMTS to WLAN occurs if it satisfies the condition given in (4.26)

$$S_{WLAN,k} > S_{UMTS,l} \tag{4.26}$$

Where k and l are used to represent the maximum of WLAN AP's and UMTS BS's respectively.

The distance and velocity of mobile node affect the service quality in vertical handoff [46]. The maximum distance from AP or BS results in weak signal strength. Similarly, the higher velocity affects the service continuity in current network and it gives rise to the need of handoff. 'q' is set as a timer to detect mobile node position periodically such as in GPS. The mean velocity '$\bar{v}$' of mobile node is given as:

$$\bar{v}_t = (1 - \alpha) \sum_{q=0}^{t} \alpha^{q-1}\, v_{q-t+1}\ , \tag{4.27}$$

where $\bar{v}$ is mean velocity of MN with respect at instant time 't' and $\bar{d}$ is average distance of MN at time 't'. α is exponential smoothing factor and $(1 - \alpha)$ is used for minimizing the values in certain limits.

Average distance of mobile node at time't' is given in (4.28)

$$\bar{d}_t = (1 - \alpha) \sum_{q=0}^{t} \alpha^{q-1}\, d_{q-t+1} \tag{4.28}$$

The Velocity function '$V_j(t)$' for j^{th} mobile node at time't' is given as in (4.29)

$$V_j(t) = \sum_{1 \leq q \leq t} (\bar{v}_t + \bar{d}_t)) \tag{4.29}$$

To minimize the ping pong effect, using eq. (4.27) the Optimum Velocity function 'O' is determined for the maximum and minimum velocity fairness. The minimum and maximum optimization of velocity is denoted by 'O_{min}' and 'O_{max}' respectively and mathematically is presented as:

$$O_{min} = \mathrm{Min}_{\forall p_{ij} \in P} \left\{ \sum_{m_j \in M} \left(V_j(t) \right) \right\} \tag{4.30}$$

$$O_{max} = \mathrm{Max}_{\forall p_{ij} \in P} \left\{ \sum_{m_j \in M} \left(V_j(t) \right) \right\} , \tag{4.31}$$

where p_{ij} is defined as a binary variable i.e. $p_{ij} \in \{0,1\}$. It is considered one, when mobile node is connected with UMTS network, and zero when it connected with WLAN.

Load as given in (4.12) and eq. (4.14), is critical issue in consistent maintenance of traffic congestion and QoS.

The total data rate 'D_i' requested from all AP'S $(1 \leq i \leq k)$ and for all BS's $(1 \leq i \leq l)$ data rate is given as:

$$D_i \ (1 \leq i \leq k + l) \tag{4.32}$$

Let r_j is the data rate request by mobile node $m_j (1 \leq j \leq \boldsymbol{M})$ then total load is given as:

$$D_i(P) = \sum_{m_j \in M} r_j \, p_{ij} \ , \tag{4.33}$$

where $P = \{p_{ij}\}_{(k+l) \times M}$ is the association matrix of UMTS coverage such that $\sum_{1 \leq i \leq k+l} p_{i,j} = 1$, for $1 \leq j \leq M$.

In terms of effective bandwidth based on eq. (4.12) and (4.14), the total requested data rate is given as:

$$D_i(P) = \begin{cases} \sum_{m_j \in M} b_{ij} \, p_{ij} & for \quad 1 \leq i \leq k \\ \sum_{m_j \in M} b_{ij}^{u} \, p_{ij} & for \quad 1 \leq i \leq k + l \end{cases} \tag{4.34}$$

Using the property that minimize sum of squared numbers is equivalent to minimizing standard deviation of the numbers when the mean is constant [79]. The total load by mobile nodes **M** is given as:

$$\sum_{1\leq i\leq k+l} D_i(P) \tag{4.35}$$

It does not change irrespective what value *P* has.

We have formulated a Load based cost function 'U' and developed the following optimization for distributed load:

$$U_{min} = Min_{\forall p_{ij}\in P} \sum_{1\leq i\leq k+l} w(i)\left(\frac{(\rho_i - D_i(p))}{\lambda_i}\right)^n , \tag{4.36}$$

where ρ_i represents the load at i^{th} access point of WLAN and UMTS BS as given in (4.12) and (4.14) respectively. The notation 'n' is used to provide fairness to load distribution and its recommended value is 2. The factor w(i) ($1\leq i \leq l$) is denoted as the predefined cost or weights for the bandwidth of AP and BS.

In expression (4.36) the $1/(k+l)\sum_{1\leq i\leq k+l} w(i)\frac{(\rho_i - D_i(p))}{\lambda_i}$ is invariant with change decision (P), where λ_i is the maximum load that a access point of WLAN or base station of UMTS can tolerate. The expression (4.36) depends on following (4.37)

$$\rho_{i+} D_i(p) \leq \lambda_i \qquad \text{for } 1\leq i \leq k+l \tag{4.37}$$

The maximum number of customer (or load) served by AP/BS is denoted by 'λ'. The maximum load tolerated by WLAN is given as:

$$\boldsymbol{\lambda}_i = \boldsymbol{\lambda}_{WLAN} , \qquad \text{for } 1\leq i \leq k \tag{4.38}$$

where $\boldsymbol{\lambda}_{WLAN}$ is used to represent the maximum load support of WLAN derived in eq. (4.12). Similarly for UMTS, $\boldsymbol{\lambda}_i$ is given as:

$$\boldsymbol{\lambda}_i = \boldsymbol{\lambda}_{UMTS} \qquad \text{for } 1\leq i \leq l \tag{4.39}$$

where $\boldsymbol{\lambda}_{UMTS}$ is used to represent the maximum load support of WLAN as derived in eq. (4.14).

The battery life denoted as $E_j(t)$ of j^{th} mobile node of set **M** is given as :

$$E_j(P,t) = \sum_{1\le i \le k+l} E_{ij}(p_{ij}) , \tag{4.40}$$

where t is time instant of energy available in MN for j^{th} node.

The joint optimization function 'C' based on Battery life, Velocity and Load with parameters α, β and γ is computed as:

$$C(P,\alpha,\beta,\gamma)=\alpha \sum_{1\le i \le k+l} E_{ij}(p_{ij})+\beta \sum_{m_j=M} (\overline{v}_t + \overline{d}_t) - \gamma \sum_{1\le i\le k+l} w(i) \left(\frac{(\rho_i - D_i(p)}{\lambda_i}\right)^n \tag{4.41}$$

Minimizing the cost function (4.33) is equivalent to maximizing the negative of cost function as $\frac{(\rho_i - D_i(p)}{\lambda_i} < 1$. Thus joint optimization is given as follow:

$$C_{max}: \text{Max } C\ (P,\alpha,\beta,\gamma) \tag{4.42}$$

The total score factor is calculated based on total load used, received signal strength and velocity

$$F = W_c * C + W_s * S + W_v * V\ , \tag{4.43}$$

where W_c , W_s and W_v are weight factors used for load 'C', signal strength 'S' and velocity 'V' respectively. The Weight factors W_c, W_s and W_v are used in such a way that they satisfy the condition $W_c + W_s + W_v = 1$.

The Velocity Adaptive Handoff 'VADH' is used giving maximum weightage to Velocity as main parameter and comparing score values derived in eq. (4.40).

Total score for current and neighboring node serving nodes i.e. BS/AP are compared and handoff is initiated and executed based on threshold value.

4.2.1 Goodput Policy Based approach

Based on data received g_i ,the goodput estimation, denoted as *GP(n)* is calculated using two methods, one is Weighted Moving Average 'WMA' method with last sample *K* and second is the Exponential Smoothing Average 'ESA' method [14] . The MN starts the goodput estimation given by

$$\mathrm{GP(n)} = \sum_{\mathrm{i=n-K}}^{\mathrm{n}} \frac{\mathrm{g_i}}{\mathrm{K}} \tag{4.44}$$

Assuming that, g_i=0, for $i < 0$, it follows that GP(n)=*0*, if n < 0. If ESA filtering [110] is considered, then the average goodput can be computed as follows:-

$$\begin{Bmatrix} \mathrm{GP(n)} = \mathrm{w_1} + \mathrm{w_2}(\mathrm{GP(n-1)}) + \mathrm{w_3}(\mathrm{GP(n-2)}) \\ \mathrm{w_1, w_2, w_3} \in [0,1] \\ \sum_{\mathrm{i}}^{3} \mathrm{w_i} = 1 \end{Bmatrix} \tag{4.45}$$

To select the target network, the network with high goodput is chosen for real time (RT) applications. For non real time (NRT), the network with good distance parameters are chosen. The format for pheromone table is given in Table 4.1 as below:-

Table 4.1: Format of Pheromone Table

Pheromone Table				
Source MN ID	Destination BS (or AP) ID	Goodput (GP)	Battery life (E)	Distance (D)

The flowchart of the proposed Velocity Adaptive Handoff (VADH) from WLAN to UMTS has been shown in Fig. 4.2. The steps involved in VADH algorithm are given below:

Step 1. For a mobile node in WLAN network, with handoff request first check the type of service whether RT or NRT.

Step 2. For real time applications check the speed of mobile node fast or slow.

Step 3. For fast MN with availability of UMTS network, execute vertical handoff else stay connected in current WLAN network.

Step 4. For RT application with slow speed MN, if UMTS is available implement VADH algorithm and compare score of WLAN and UMTS. If total score of UMTS is greater than WLAN execute vertical handoff else stay connected in current WLAN network or send vertical handoff fail information for start search again. If UMTS not available send vertical handoff fail information for slow speed MN.

Step 5. For NRT application with availability of UMTS network apply VADH algorithm and compare score of UMTS and WLAN if score of WLAN is found greater than WLAN execute vertical handoff else stay connected in current WLAN network.

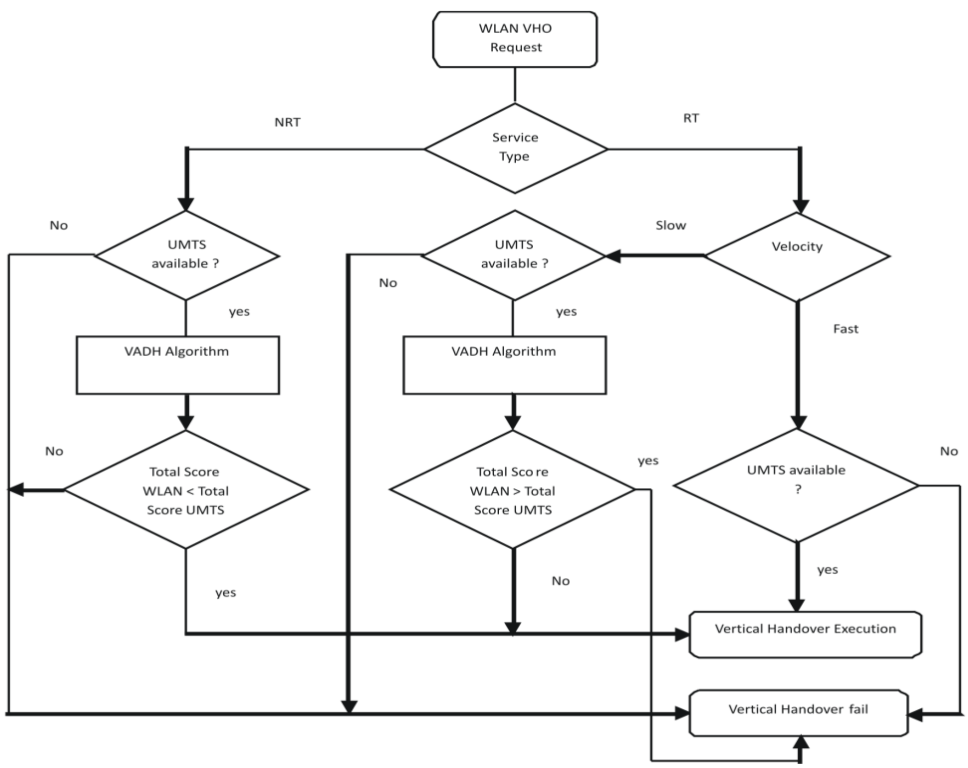

Fig: 4.2 Proposed VADH Algorithm for WLAN to UMTS Handoff

To estimate the weight of each decision factors Simple Additive Weighting (SAW) method [95] has been used in proposed VADH. The available information obtained from the network and MN is converted to a quantitative value. A suitable network is used based on Analytic Hierarchy Process (AHP) method [94]. Based on the type of service and velocity, the flow chart for proposed VADH algorithm for UMTS to WLAN is shown in Fig. 4.3.

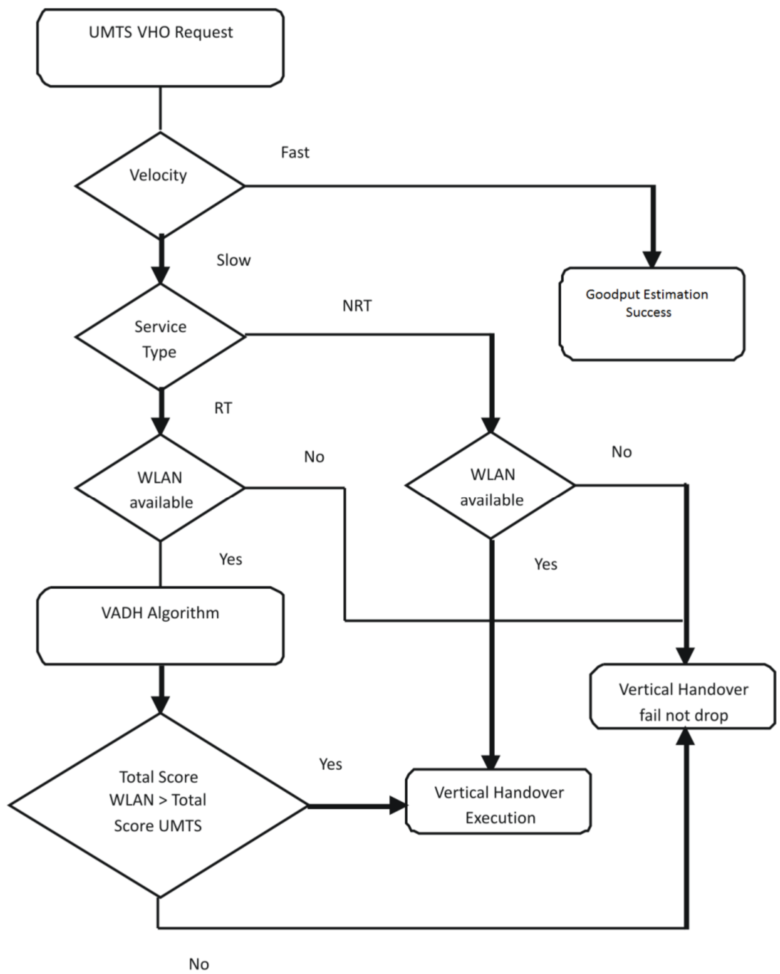

Fig: 4.3 Proposed VADH Algorithms for UMTS to WLAN Handoff

Step 1. Initially check the handoff request in UMTS connection. Check the velocity of mobile node if it is fast than perform goodput estimation policy.

Step 2. For slow speed check the type of service type if it is RT or NRT. For real time application, check the availability of WLAN network, if condition is satisfied, implement VADH algorithm and compare the total score of two access technology. If score of WLAN is greater than UMTS execute vertical handoff, else stay connected in current UMTS network or send start search again request.

Step 3. For NRT application, with availability of WLAN network execute vertical handoff else stay connected in current UMTS network

4.3 Proposed Architecture

Fig. 4.4 demonstrates the proposed architecture of WLAN-UMTS. The WLAN coverage zones are enclosed within UMTS coverage zone. Initially, MNs are present only in the UMTS coverage zone. The Vertical Handoff Controllers 'VHC' are located in IEEE 802.21 access networks that offer vertical handoff decision.

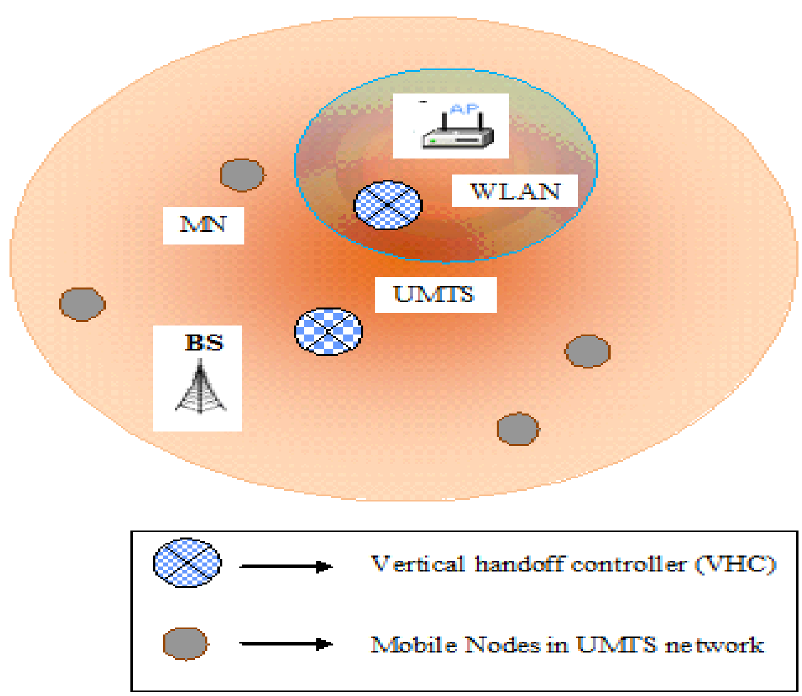

Fig: 4.4 Proposed Architecture for WLAN/UMTS

4.4 Simulation Model and Parameters

To evaluate the proposed solution against other approaches, we have implemented it in an appropriate simulation environment as given in Table 4.2 [120]. The simulation engine NS-2 version 2.29 [85] with NIST add-on modules has been used [121]. However, the VHO algorithm implemented by the NIST in the version 2.29 of NS-2 only considers the RSS for the decision making. We have implemented this in ns-2 to support our proposed swarm based approach. We have extended the modules such that all heterogeneous interfaces of the MN can be collected. A MN is provided with dual-network interface capability. The simulation settings and parameters are summarized in Table 4.2.

Table 4.2: Simulation Settings and Parameters

Simulation parameters	**Scenario1**
Area Size	3000 m X 3000m
Number of Users	20
Transmission range of UMTS	1000 (meter)
Transmission range of WLAN	100 (meter)
$MinThrs_{UMTS}$ & $MaxThrs_{UMTS}$	-80 to -75 (dbm)
$MinThrs_{WLAN}$ & $MaxThrs_{WLAN}$	-95 to -92 (dbm)
Traffic Source	CBR
Mobility model	Random way point
Velocity of MN	1 to 20 mps
Number of UMTS base station	1
Number of WLAN access point	2

UMTS has 1 km radius. Inside macro cell UMTS, two WLANs are located, with 100m radius. The transmit power of BSs is 1 Watt and the transmit power of APs is 100 mWatt.

4.5 Results and Discussions

4.5.1 Result Analysis for Scenario 1

We have simulated the scenario 1 as mentioned in Table 4.2 for our proposed Smart Routing based Vertical Handoff Approach (SR-VADH), Data Rate based Vertical Handoff Approach (DR-VADH), Fuzzy Based Vertical Handoff Approach (FBVAH) as well as Ordinary Vertical Handoff Approach (OVAH). To study the behavior of the different approaches under various QoS parameters, the numbers of users are varied from 1 to 10 and mobile node speed is also varied from 1 to 15 mps. Fig. 4.5, 4.6 and 4.7 respectively shows the comparison of packet loss, handoff probability and average delay response achieved based on load.

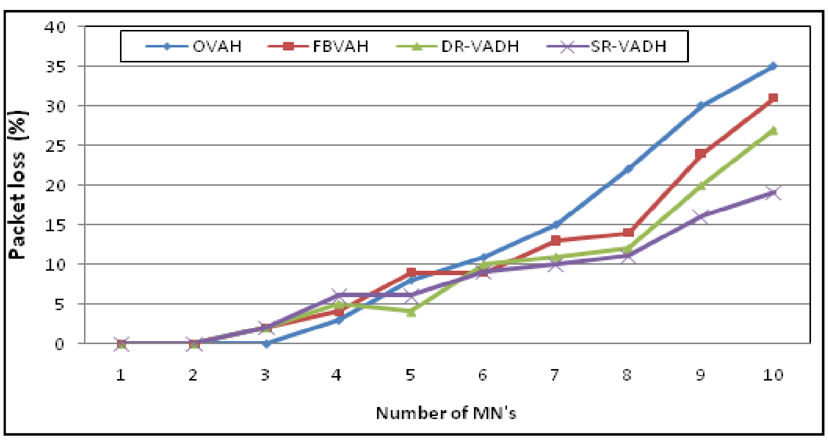

Fig: 4.5 Packet Loss with Increasing Number of MN Users

Fig. 4.5 shows the variation in packet loss with increasing load i.e. number of users. It has been observed that OVAH approach delivers packets with maximum loss as this approach uses only received signal strength. The FBVAH approach performs better than OVAH approach. The DR-VADH approach is observed to be better than OVAH and

FBVAH. The SR-VADH approach is found better than all approaches. It also manages and maintains the packet loss consistently between 6 and 8. The packet loss in SR-VADH has been observed better at 8 to 10 as compared to all other approaches,.

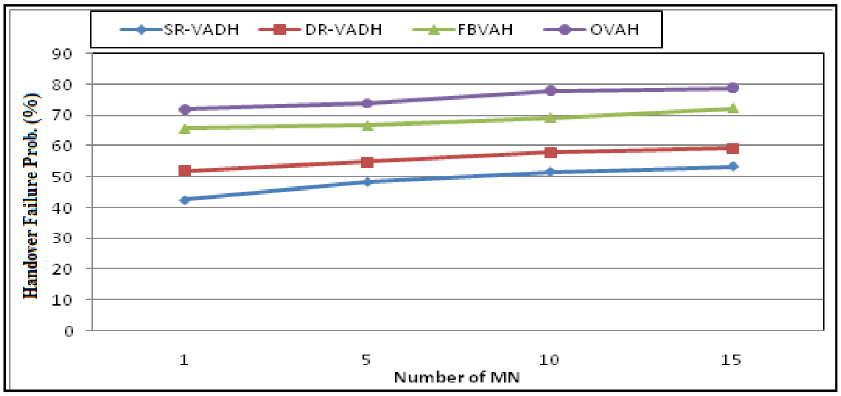

Fig: 4.6 Handoff Probabilities with Increasing Number of MN Users

Fig. 4.6 shows the variation in handoff failure probability with increasing number of mobile nodes. OVAH approach gives maximum handoff failure probability. The FBVAH approach performs better than OVAH approach. The handoff failure probability in DR-VADH approach is observed better than both OVAH and FBVAH. Further handoff failure probability in proposed SR-VADH approach has been found best amongst all, which is required to reduce the unnecessary handoffs.

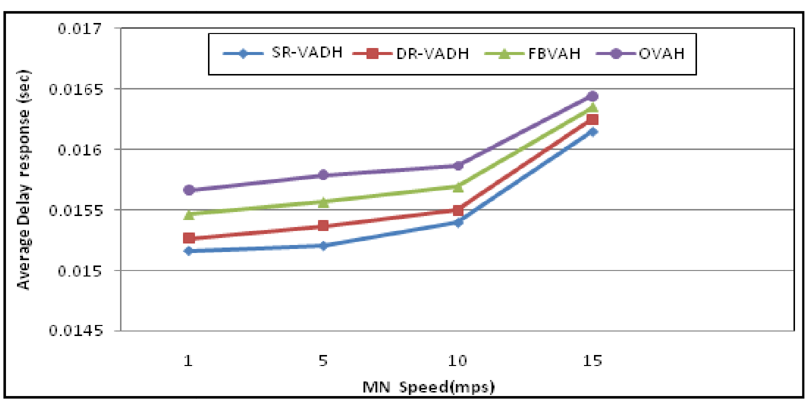

Fig: 4.7 Delay Response Vs Mobile Node Speed

As shown in Fig. 4.7, the average delay has been observed and compared for all approaches with increasing MN speed. It has been found that proposed SR-VADH s better than DR-VADH, FBVAH and OVAH.

4.5.2 Result Analysis for Scenario 2

To evaluate the QoS parameters the simulation parameters for scenario 2 are given in Table 4.3. The end to end delay, jitter and throughput are measured and compared for proposed smart routing vertical handoff approach (SR-VADH) with Data Rate based Vertical Handoff Approach (DR-VADH).

Table 4.3: Simulation Settings and Parameters

Simulation parameters	**Scenario 2**
Area Size	1000 m X 1000 m
Base stations/AP	2
Number of Users	5
Transmission range of UMTS	500 (meter)
Transmission range of WLAN	100 (meter)
$MinThrs_{UMTS}$ & $MaxThrs_{UMTS}$	80 to -75 (dbm)
$MinThrs_{WLAN}$ & $MaxThrs_{WLAN}$	-95 to -92 (dbm)
Mobility Model	Straight line
Velocity of MN	1 to 15 mps
Number of UMTS base station	1
Number of WLAN access point	1

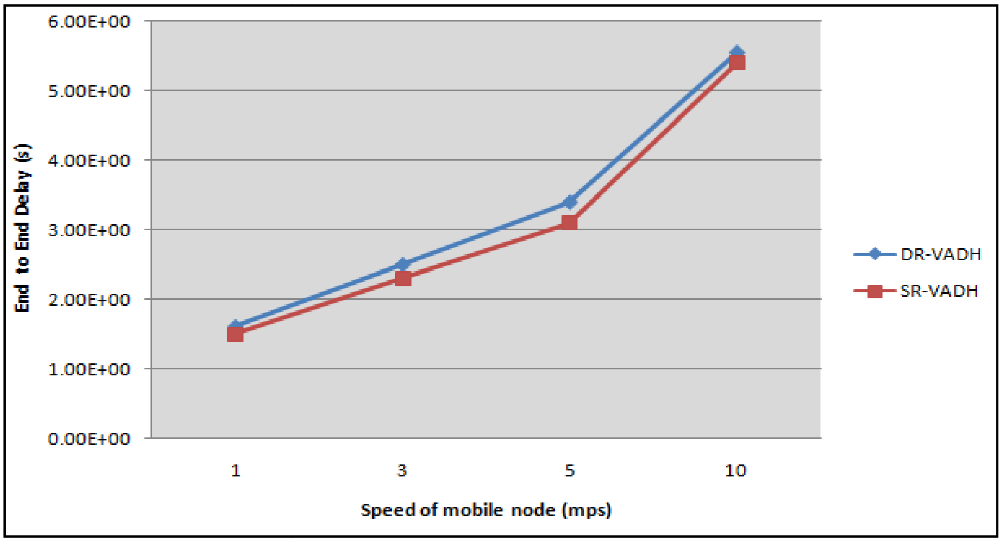

Fig: 4.8 End to End Delay Response Vs Speed of Mobile Node

The end to end delay response has been shown in Fig. 4.8. It has been observed that proposed SR-VADH is giving better response as compared to DR-VADH approach. The end to end delay is also increasing with increase in mobile node speed. It has been observed that SR-VADH has lower end to end delay as compared to DR-VADH.

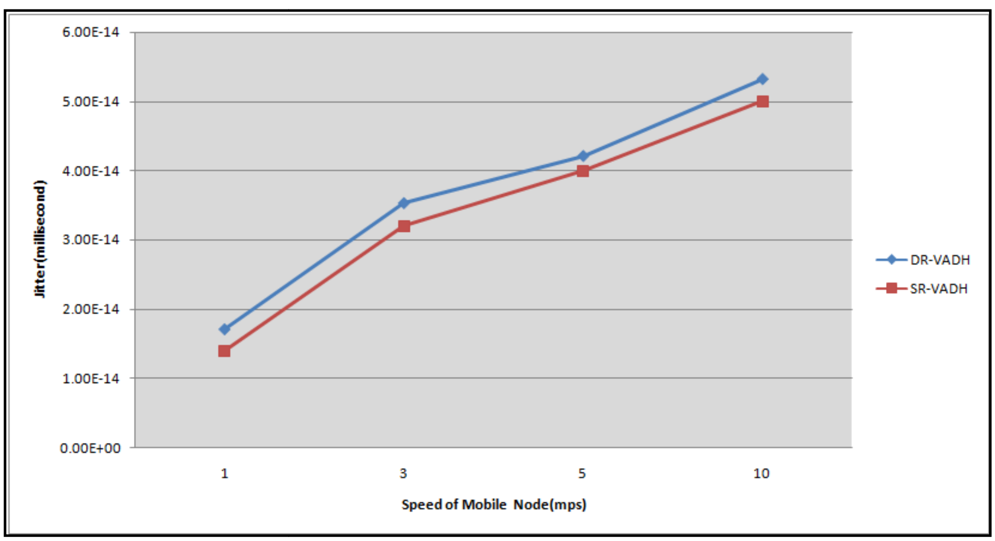

Fig: 4.9 Jitter Response Vs Speed of Mobile Node

Jitter response is defined as the packet delay variation. As depicted in Fig. 4.9, with variation in MN speed, the jitter has been observed better in proposed SR-VADH approach as compared to DR-VADH approach.

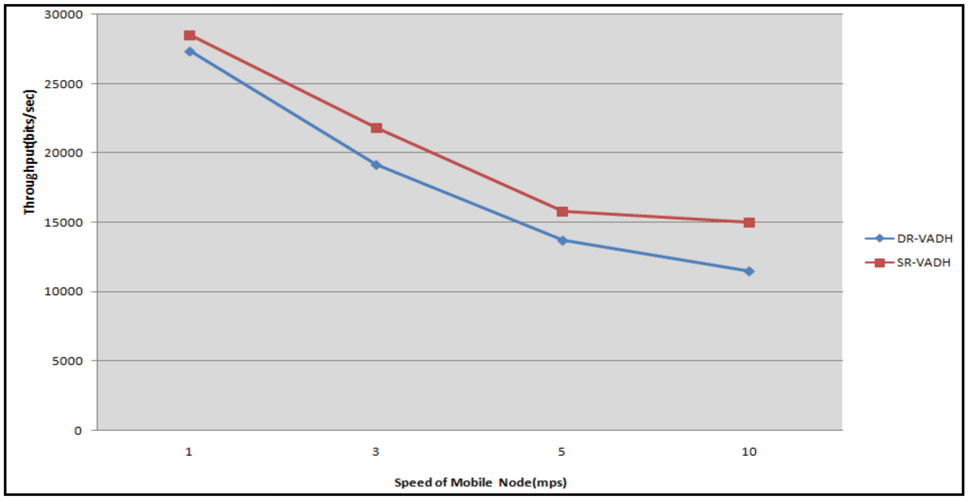

Fig: 4.10 Throughput Response Vs Speed of Mobile Node

The throughput response is shown in Fig. 4.10. It has been observed that the proposed SR-VADH approach is giving better throughput response as compared to DR-VADH approach.

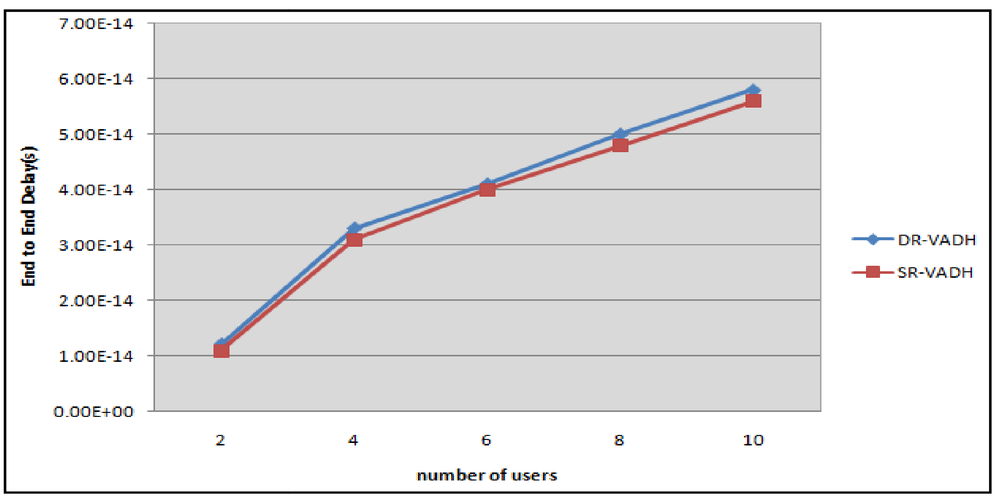

Fig: 4.11 Delay Response Vs Number of Users

The end to end delay response has been shown in Fig. 4.11 for varying load. It has been observed that the proposed SR-VADH as compared to DR-VADH approach. By varying load, the end to end delay has been observed minimum in SR-VADH as compared to DR-VADH approach.

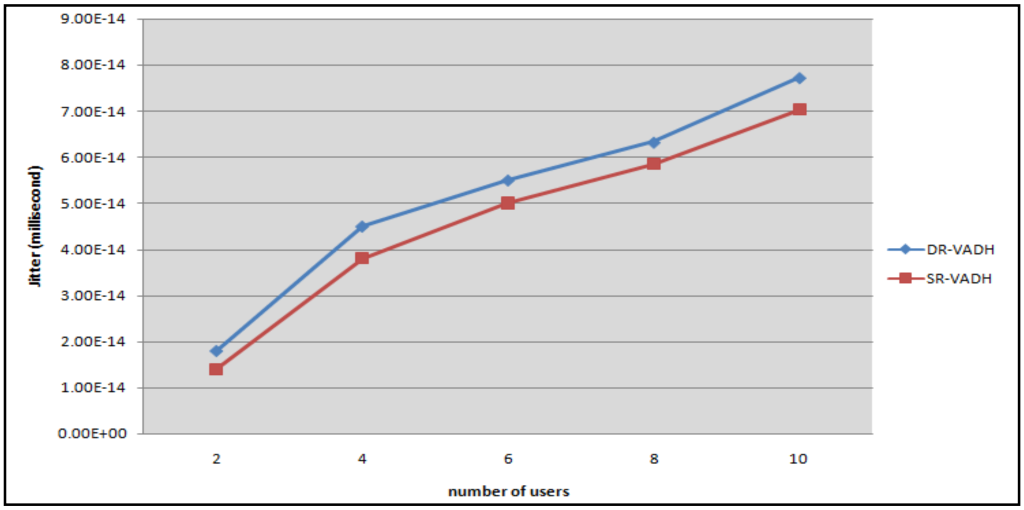

Fig: 4.12 Jitter Response Vs Number of Users

As shown in Fig. 4.12, the jitter response has been observed better in proposed SR-VADH approach as compared to DR-VADH approach. The minimum jitter has been observed in SR-VADH which is desirable for achieving the QoS.

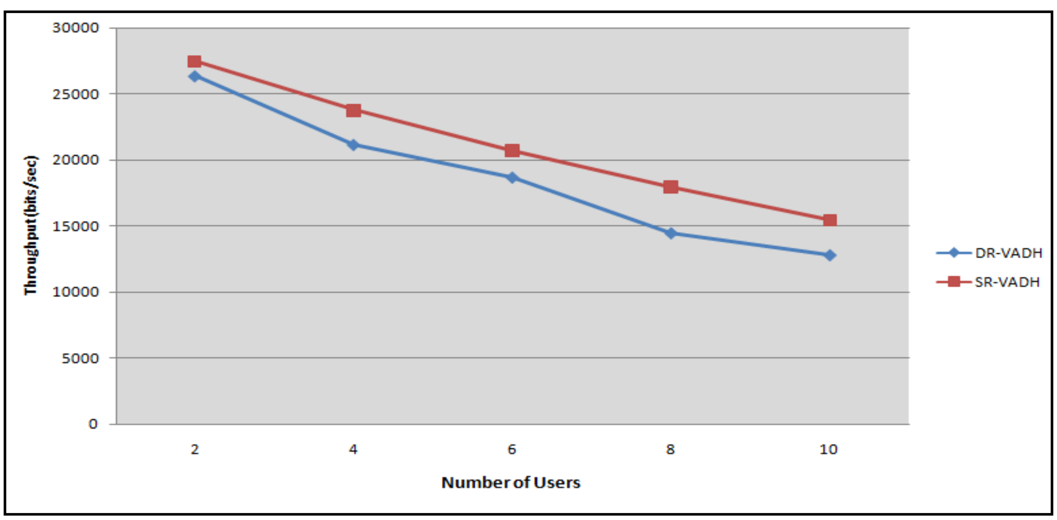

Fig: 4.13 Throughput Response Vs Number of Users

As shown in Fig. 4.13, throughput has been observed better in proposed SR-VADH approach as compared to DR-VADH approach. In SR-VADH, throughput is decreasing with variation in load. It has been observed that throughput is improving consistently with load as compared to DR-VADH approach.

In this Chapter, we have discussed the vertical handoff scenario for WLAN-UMTS. In first scenario, the proposed Smart Routing Vertical Handoff Approach (SR-VADH) is analyzed with varying number of users and speed of mobile node. It has been observed that proposed SR-VADH is better as compared to Data Rate based Vertical Handoff Approach (DR-VADH), Fuzzy based Vertical Handoff Approach (FBVAH) and Ordinary Vertical Handoff Approach (OVAH). In second scenario, the proposed SR-VADH approach is compared with data rate approach and found better for varying number of users and mobile nodes speed. In next Chapter, the vertical handoff in WiMAX-UMTS is presented.

Chapter 5

WiMAX-UMTS Vertical Handoff

5.1 Proposed Optimal and QoS based Vertical Handoff Decision

The availability of a network is detected with estimation of signal strength [107-119]. The received signal strength is defined as a measurement of the power present in a received radio signal. RSS is used to compare the strength of signal of different radio access technologies received at MN.

The set of WiMAX base stations [BS] is represented as **Z**, as given in (5.1)

$$\mathbf{Z} = [\mathrm{BS}_1, \mathrm{BS}_2, \mathrm{BS}_3, \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots ., \mathrm{BS}_z], \tag{5.1}$$

where z is total number of base stations in WiMAX. The relative signal strength 'S^{z}_{wimax}' of WiMAX is given as:

$$S^{z}_{wimax} = \frac{R^{c}_{wimax} - R^{ith}_{wimax}}{R^{max}_{wimax} + R^{ith}_{wimax}}, \tag{5.2}$$

where R^{ith}_{wimax} is the receiver threshold in WiMAX. R^{max}_{wimax} is the maximum transmitted signal strength of WiMAX. R^{c}_{wimax} is the current received signal strength of WiMAX given as:

$$R^{c}_{wimax} = R^{max}_{wimax} - 10\eta \log (d_{wimax}), \tag{5.3}$$

where η path loss exponent and d_{wimax} is separation between the mobile node and WiMAX base station in meters.

The receiver threshold in WiMAX is given as:

$$R^{ith}_{wimax} = R^{max}_{wimax} - 10\eta \log (D_{wimax}), \tag{5.4}$$

where D_{wimax} is reference distance for RSS measurement from WiMAX base station .

Using (5.3) and (5.4) relative signal strength for WiMAX is given as:

$$S^{z}_{wimax} = 1 - \frac{\log(d_{wimax})}{\log(D_{wimax})}, \quad (5.5)$$

we have calculated S^{Y}_{wimax} for all base station of WiMAX, i.e. **Z** = {1, 2, 3… z}.

Similarly as derived in (4.22) section 4.2, the relative signal strength for UMTS is given as:

$$S^{Y}_{umts} = 1 - \frac{\log(d_{umts})}{\log(D_{umts})}, \quad (5.6)$$

we have calculated S^{X}_{umts} for all base station of UMTS, i.e **Y**= {1, 2…………, *l}*. where *l* is total number of base stations in UMTS.

The average value of signal Strength at any point *x* connected with UMTS or WiMAX BS is given as $s_{umts}(x)$ and $s_{wimax}(x)$ respectively. The log normal distribution expressions of UMTS average signal strength is given as:

$$\overline{s_{umts}(x)} \sim N[\mu_{umts}, \sigma^2_{umts}] \quad (5.7)$$

The log normal distribution expressions average signal strength of WiMAX is given in (5.8)

$$\overline{s_{wimax}(x)} \sim N[\mu_{wimax}, \sigma^2_{wimax}], \quad (5.8)$$

where μ_{umts} and μ_{wimax} are mean signal levels of UMTS and WiMAX respectively. σ^2_{umts} and σ^2_{wimax} are shadowing standard deviation of UMTS and WiMAX respectively. We have assumed a stationary random process with normal distribution. The total amount of bandwidth available at time *t*, along any connection can be estimated using wireless signal strength. The available bandwidth 'B' at a link is the idle capacity. The available bandwidth [106] at WiMAX link at time *t* is given in (5.9)

$$B_{wimax}(t, T) = \frac{1}{T}\int_{t}^{T+t} C_{WIMAX}(1-\varepsilon_{WIMAX}(t))dt, \quad (5.9)$$

where C_{wimax} and $\varepsilon_{WIMAX}(t)$ are capacity and percentage of link utilized respectively, of WiMAX network.

Total load associated in WiMAX is calculated as

$$\rho_{wimax}= \sum_{j\epsilon M} B_{wimax,j} , \tag{5.10}$$

where $B_{wimax,j}$ is the effective bandwidth of mobile node m_j, when it is connected with WiMAX base station. The available bandwidth at WiMAX link at time'‘t’ is given as:

$$B_{umts}(t,T) = \frac{1}{T}\int_{t}^{T+t} C_{umts}\left(1 - \varepsilon_{umts}(t)\right)dt, \tag{5.11}$$

where C_{umts} and $\varepsilon_{umts}(t)$ are capacity and percentage of link utilized respectively, of UMTS network. The total load on UMTS network is given as

$$\rho_{umts} = \sum_{j\epsilon M} B_{umts,j} , \tag{5.12}$$

where $B_{umts,j}$ is the effective bandwidth of mobile node m_j, when it is connected with UMTS base station. Based on comparison between signal strength ‘S’, goodput ‘GP’ of serving AP/BS and available bandwidth ‘B’ handoff is initiated and executed. If following condition is satisfied then handoff is executed from WiMAX to UMTS.

$$[\ \overline{s_{wimax}(x)} \geq \overline{s_{umts}(x)}\ ] \text{ and } [\ GP_{wimax} \geq GP_{umts}\ ] \text{ and } [\ B_{wimax} \geq B_{umts}\ ] \tag{5.13}$$

The vertical handoff will occur if the following condition will be satisfied from WiMAX to UMTS.

$$[\ \overline{s_{umts}(x)} \geq \overline{s_{wimax}(x)}\ ] \text{ and } [\ GP_{umts} \geq GP_{wimax}\ ] \text{ and } [\ B_{umts} \geq B_{wimax}\ ] \tag{5.14}$$

Thus, based on RSS, B and GP of serving network technology; best network is selected as discussed in next section.

5.1.1 Vertical Handoff Initiation

For perfect communication at any given time it is necessary to arrange suitable connection point (BS or AP) for every MN. To ensure continuous service, the vertical handoff process is necessary [107-115]. In vertical handoff, the Media Independent Handoff Function (MIHF) of IEEE 802.21 is used for exchanging the link layer information MNs RSS 'S' and load 'U' (as in (4.36) section 4.2) values among different networks [107]. The MIHF at an access point maintains the current RSS and load information of MNs. The Swarm Vertical Handoff Controller (SVHC) used in proposed approach assists in optimizing the performance of the integrated system of available networks, specifically in terms of RSS and load balancing. Link Layer Triggers (LLT) is also used that indicates the possible status of MN [108]. At any time instant the status is given in terms of information such as RSS of MN with respect to service either at AP or BS. Status is monitored for particular threshold vale denoted as 'Th' for RSS and load. The information is updated when the RSS and load from one or more APs exceeds the threshold value 'Th' during which the service node is BS. The steps involved in the vertical handoff initiation are as follows.

1) Initially, SVHC acquires LLT's of MN through MIHF.

$$\text{MIHF} \xrightarrow{LLT} \text{SVHC}$$

2) SVHC upon receiving LLT verifies the status of MN.

 If $(S < S_{th}) \parallel (U < U_{th})$

 Then

  SVHC investigates other networks for connection handoff

  If multiple APs exists

  Then

SVHC assess the APs and initiate the handoff process to the respective network with optimal performance.

Else

WLAN is taken into consideration as best network for initiating handoff.

End if

Else

MN initiates handoff from a BS (UMTS or WiMAX) to an AP (WLAN)

End if.

Here symbol ‘||’ is used to represent parallel operation. Following the vertical handoff initiation, the ant based route discovery is performed. The forward ant (FA) visits each BS and its movement is based on probabilistic decision rule (using eq. 3.14). Using this rule, FA moves through BS and gathers its status that includes goodput, bandwidth, battery lifetime and distance which is stored in its pheromone table. The format for pheromone table is given in Table 5.1

Table 5.1 – Format of Pheromone Table

Source MN ID	Destination BS (or AP) ID	Bandwidth (BW)	Goodput (GP)	Battery lifetime (E)	Distance (D)

Each FA deposits a quantity of pheromone ($\Delta\mu^{g}(k)$) in the visiting AP or BS according to following equation.

$$\Delta\mu^{g}(k) = 1/\, V_{s}^{g}(k), \tag{5.14}$$

where $V_{s}^{g}(k)$ is used for base stations visited by FA during movement with iteration k and g = 1, 2….n. Following the collection of routing information, the source MN, performs vertical handoff execution based on category of application [77].

Case 1: If Application = Real time (say inelastic)

Then

The network with high bandwidth is chosen as target network for executing handoff

End if

Case 2: If application = Elastic

Then

The network with good battery lifetime and distance is chosen as target network for handoff execution

End if

In vertical handoff algorithm the list of available networks is updated. The RSS and score of target network are compared with current network. A timer is set to get information related to parameters and VAH algorithm is executed if conditions get satisfied. The velocity adaptive handoff algorithm for WLAN-WiMAX- UMTS is described as:

```
Loop
If F serv_AP/BS > Ftarget_BS/AP then
If (RSS_targetBS/AP < RSS_threstagetBS/AP) then
//condition satisfied start time counter
Start counter (t_c);
if (condition remains same until counter time expires) then
//execute handover
VAH-HANDOVER(target (X(AP) or Y( BS));
else
Reset counter (tc)
end if
else
// stay in current serving BS/AP
Continue;
endif
// current BS/AP rss is weak
else If (RSS_targetBS/AP < RSS_threstagetBS/AP) then
//condition satisfied start time counter
Start counter (t_c);
if (condition remains same until counter time expires) then
//execute handover
VAH-HANDOVER (target (X(AP) or Y(?BS));
else
Reset counter (tc);
end if
end if
end loop
```

Timer is reset for checking again the parameters of serving AP/BS and parameters of target AP/BS. If parameters of serving AP/BS are not found greater than the parameters of target AP/BS, than mobile node is required to remain connected with current network. The proposed approach is optimized with particle swarm optimization technique [109].

5.1.2 Proposed Architecture for Heterogeneous Network

Fig. 5.1 demonstrates the proposed architecture. The WLAN and WiMAX coverage zones are enclosed within UMTS coverage zone. A WiMAX coverage zone overlaps with WLAN coverage zones.

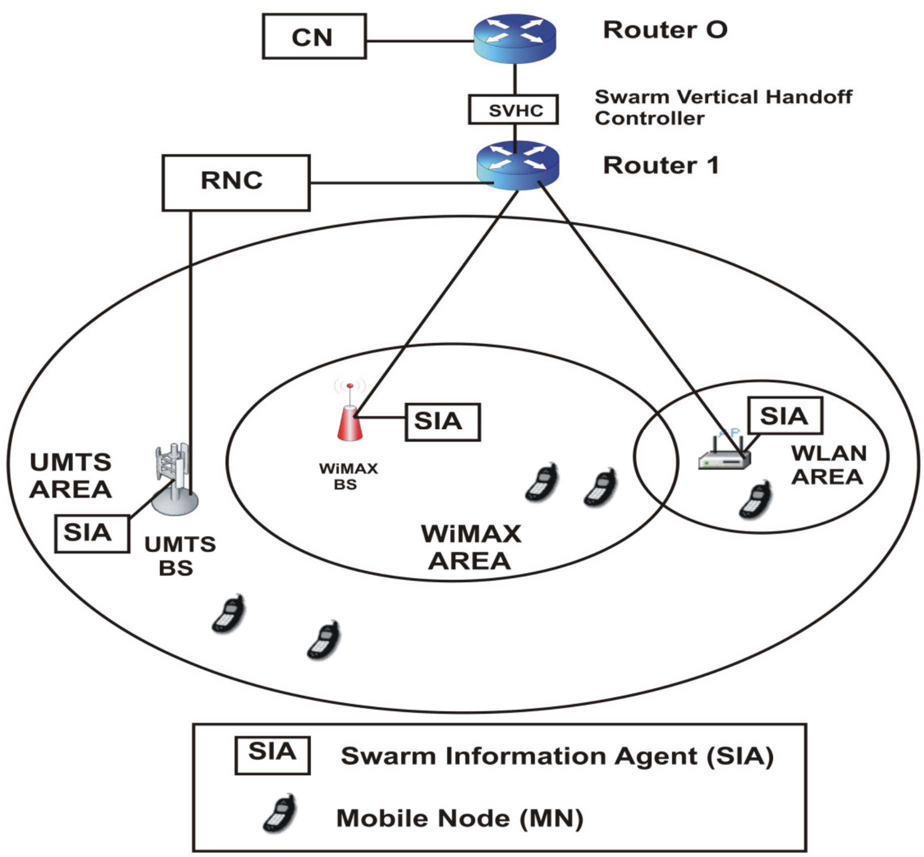

Fig: 5.1 Proposed Architecture for Heterogeneous Network

The terminologies used in this approach are as follows

BS – Base station

AP – Access Point

SVHC – Swarm Vertical handoff controller

CN – Computer Network

Initially, MNs are present only in the UMTS coverage zone. However, there is a possibility that MN can travel to the adjacent coverage zones such as WiMAX BS and 802.11 WLAN AP owing to mobility. Based on information collected from Smart Information Agents (SIA) located in access networks BS's and AP'S performs SVHC initiate and execute handoff.

5.2 Simulation model and parameters for Scenario 1

To evaluate our solution against other approaches, we have implemented it in an appropriate simulation environment [120]. The simulation engine NS-2 version 2.29 with NIST add-on modules has been used. As shown in Fig. 5.2, UMTS has 1 km radius. Inside macro cell UMTS, one WiMAX is located, with 500m radius. The transmit power of BSs is 1 Watt and the transmit power of APs is 500mWatt. A MN is provided with dual- network interface capability.

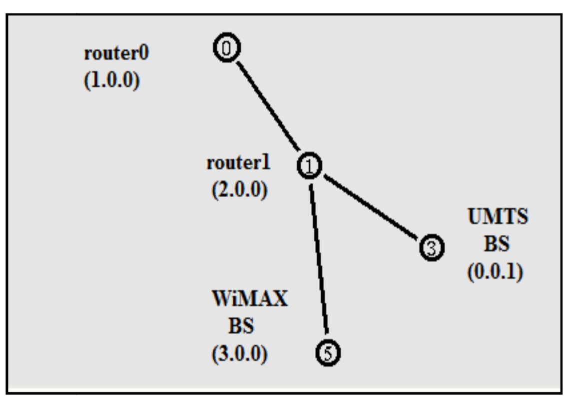

Fig: 5.2 Simulation Topology Scenario 1

The simulation settings and parameters are summarized in Table 5.2.

Table. 5.2 Simulation Settings and Parameters

Area Size	1000 m X 1000 m
Base stations	2
Number of users	25
Simulation Time	100 sec
Mobility model	Random way point
Velocity of MN	1 to 20 mps
No. of UMTS BSs	1
No. of WiMAX BSs	1

5.3 Result and Discussions for Scenario 1

For simulation parameters given in Table 5.2, the proposed Optimal and QoS based Vertical Handoff Decision (OQVHD) has been compared with the Route-Selection Algorithm (RSA) [79]. The resulting analysis has been performed on the basis of two parameters load (or the number of users) and mobile node speed.

5.3.1 Performance analysis Based on load

As shown in Fig. 5.3, it has been observed that delay increases as number of users are increased. The delay is observed better for OQVHD as compared to RSA approach. This is because the OQVHD approach is swarm based routing technique which uses optimum parameters selection and evaluation criterion for handoff selection.

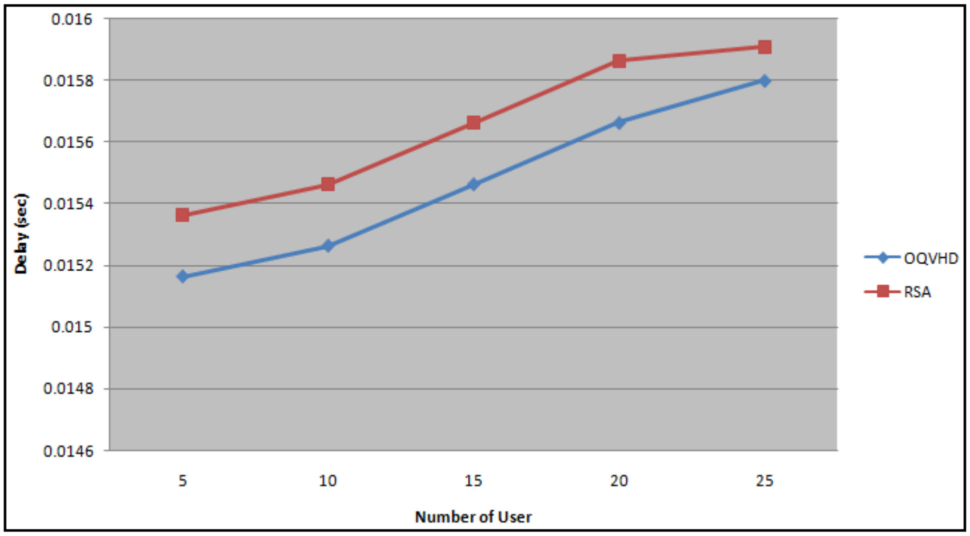

Fig: 5.3 Delay Response Vs Number of Users

Form Fig. 5.4, it has been observed that the jitter response is better in proposed OQVHD as compared to RSA approach for varying number of users from 5 to 25. Jitter performance has been observed better for 5 to 20 numbers of users as compared to RSA approach. This is because the shortest path with better QoS serving node is selected for handoff.

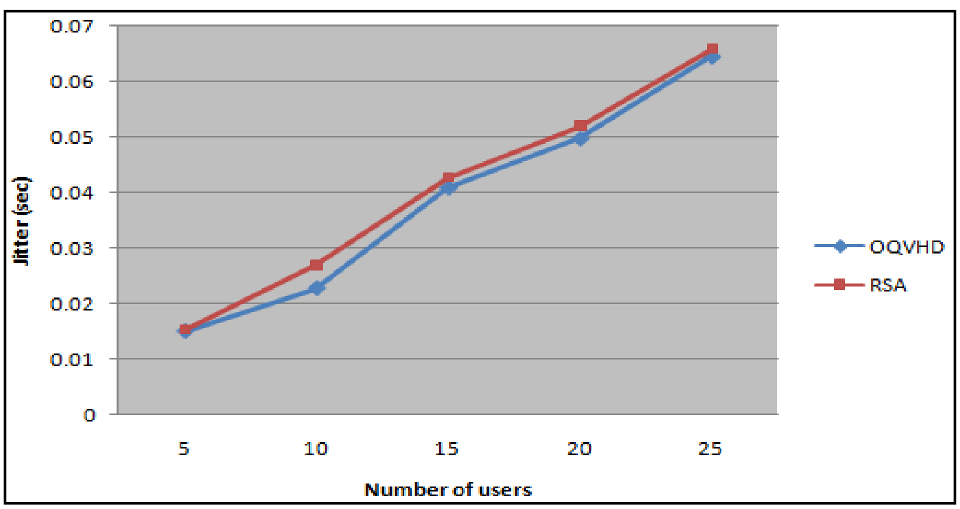

Fig: 5.4 Jitter Response Vs Number of Users

As shown in Fig. 5.5, throughput response has been observed for varying number of users from 5 to 25. The throughput has been found better in proposed OQVHD as compared to RSA approach. It is due to better goodput, maximum bandwidth utilization and minimum load selection in proposed OQVHD.

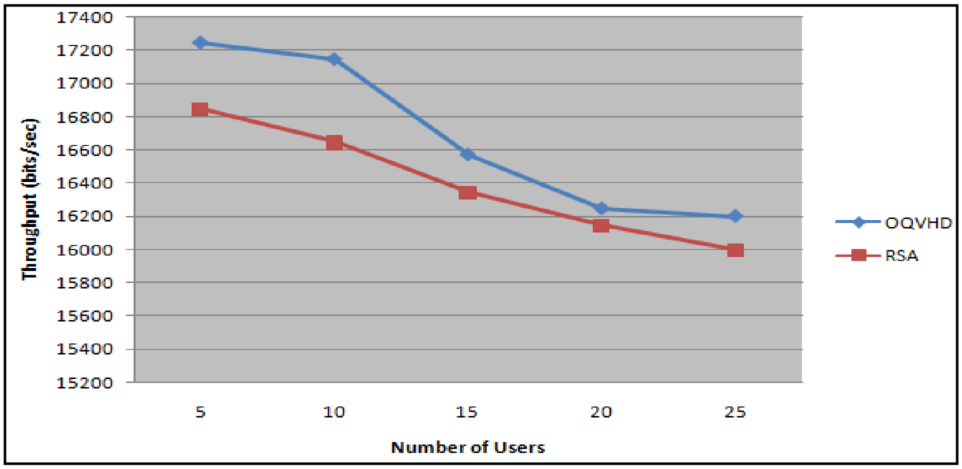

Fig: 5.5 Throughput Response Vs Number of Users

5.3.2 Performance analysis Based on Speed

The QoS parameters delay, jitter and throughput are analyzed based on mobile node speed varying from 1 to 15 meter per second (mps). From Fig. 5.6, it has been observed that the delay response decreases with increasing mobile node speed.

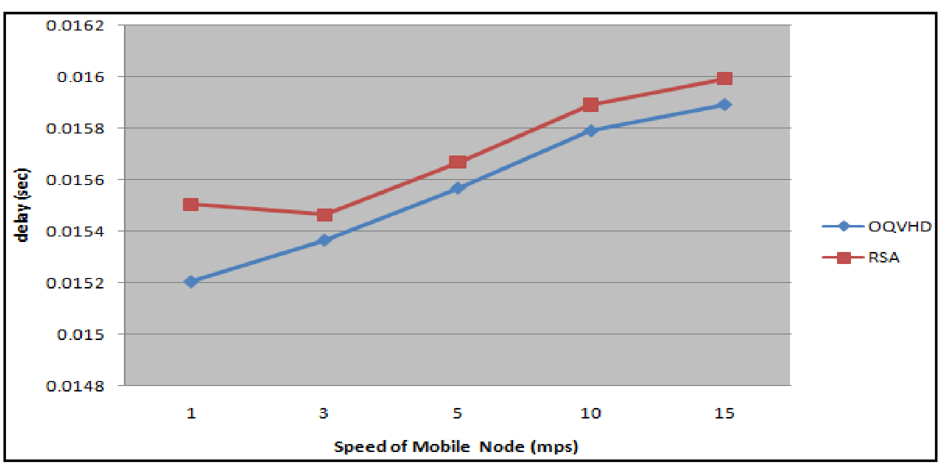

Fig: 5.6 Delay Response Vs Speed of Mobile Node

With fast speed of mobile node due to ping-pong effect surplus handoff take place, thus it gives rise to increase in delay. It has been observed that proposed OQVHD approach is giving better results as compared to RSA approach. In proposed approach, better response for delay is observed at a speed of 1 mps. This is because speed is very low and mobile node gets enough time to decide handoff. Condition of ping- pong effect gets minimized at slow speed.

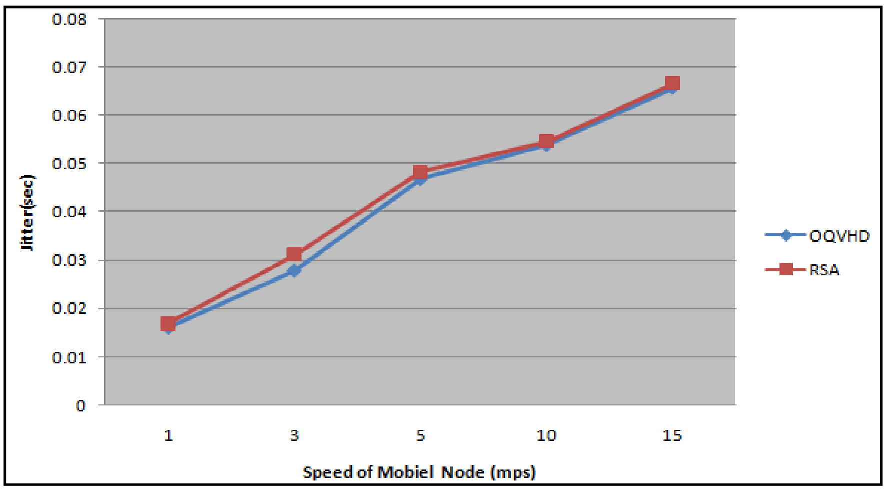

Fig: 5.7 Jitter Delay Response Vs Speed of Mobile Node

In Fig. 5.7 jitter response for proposed OQVHD approach is compared with RSA approach with varying mobile speed from 1 to 15 mps. It has been observed that proposed OQVHD approach is giving better results as compared to RSA approach. Better performance has been observed at MN speed upto 3 mps.

It is depicted from Fig. 5.8 that throughput decreases with increasing mobile node speed. The throughput response for proposed OQVHD has been observed better as compared to RSA approach.

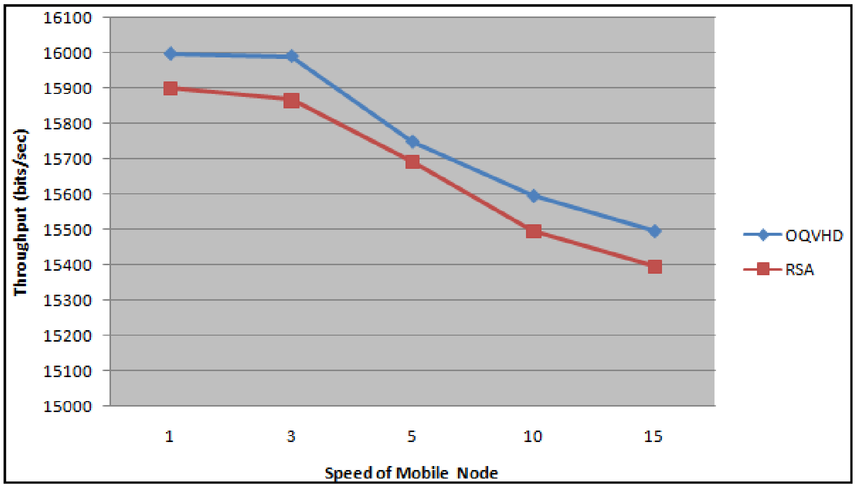

Fig: 5.8 Throughput Response Vs Speed of Mobile Node

Throughput has been obtained better in proposed approach with swarm optimization technique due to availability of maximum bandwidth and goodput estimation.

5.4 Simulation topology scenario 2

To simulate the proposed OQVHD approach, NS-2 [85] has been used. During simulation, clients (SS) and the base station (BS) are deployed in a 3000 meter x 3000 meter region as shown in Fig. 5.9.

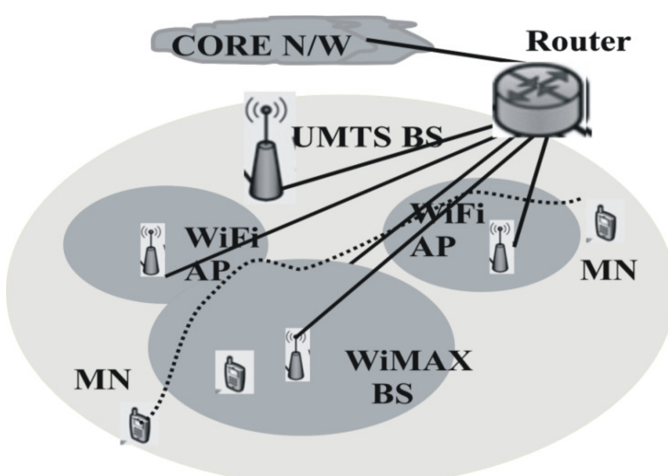

Fig: 5.9 Simulation Topology Scenario 2

It consists of 3 base stations among which BS1 is based on UMTS, BS2 is based on 802.16 WiMAX and remaining BS3 and BS4 are based on WLAN. The simulation settings and parameters are summarized in Table 5.3.

Table. 5.3: Simulation Settings and Parameters

Simulation parameters	Scenario1
Area Size	3000 m X 3000m
Number of Users	20
Transmission range of UMTS	1000 (meter)
Transmission range of WLAN	100 (meter)
Transmission range of WiMAX	500 (meter)
No. of UMTS BSs	1
No. of WiMAX BSs	2
No. of WLAN APs	2
Mobility model	Random way point
Velocity of MN	1 to 20 mps
Traffic Source	CBR and Video
No. of CBR Flows	4
No. of Video Flows	2
Video Trace File	JurassikH263-256k_trace.dat

5.5 Result and Discussions for Scenario 2

Fig. 5.10, 5.11 and 5.12 are used to depict the average delay, jitter response and throughput response with respect to MN speed and number of access points of WLAN and base station WiMAX respectively.

As shown in Fig. 5.13, the average delay response is analyzed for speed from 1 mps to 15 mps for varying number of AP and BS of WLAN and WiMAX respectively. It has been observed that delay is decreases with increase in number of access point and base station. Delay is observed maximum for one AP and one BS and minimum for two AP and two BS. This is because of increase in serving AP or BS which also increases the number of paths for data transfer..

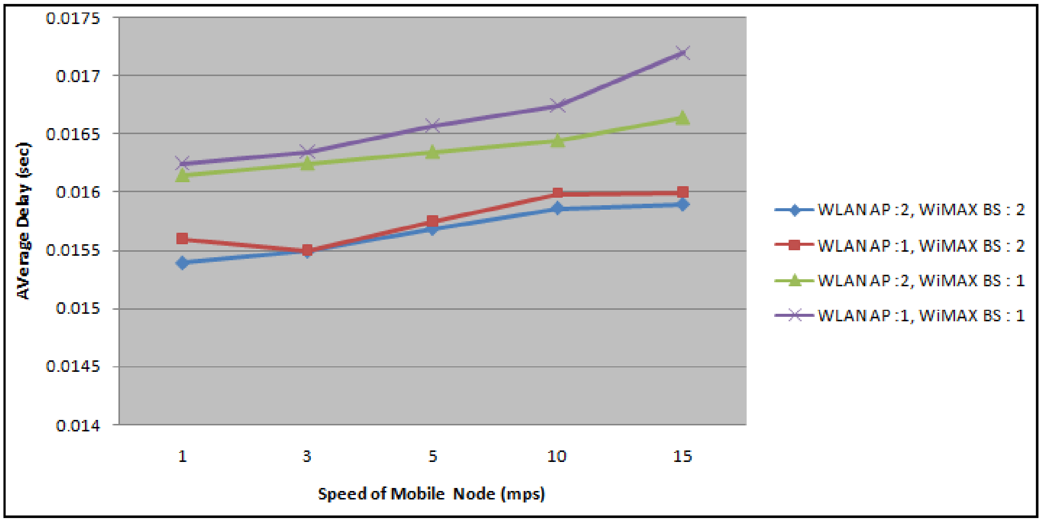

Fig: 5.10 Average Delay Response Vs Speed of Mobile Node

In Fig. 5.11 Jitter is analyzed for proposed OQVHD approach for varying speed and number of AP and BS. The jitter has been observed improved for increasing number of AP and BS of WLAN and WiMAX respectively.

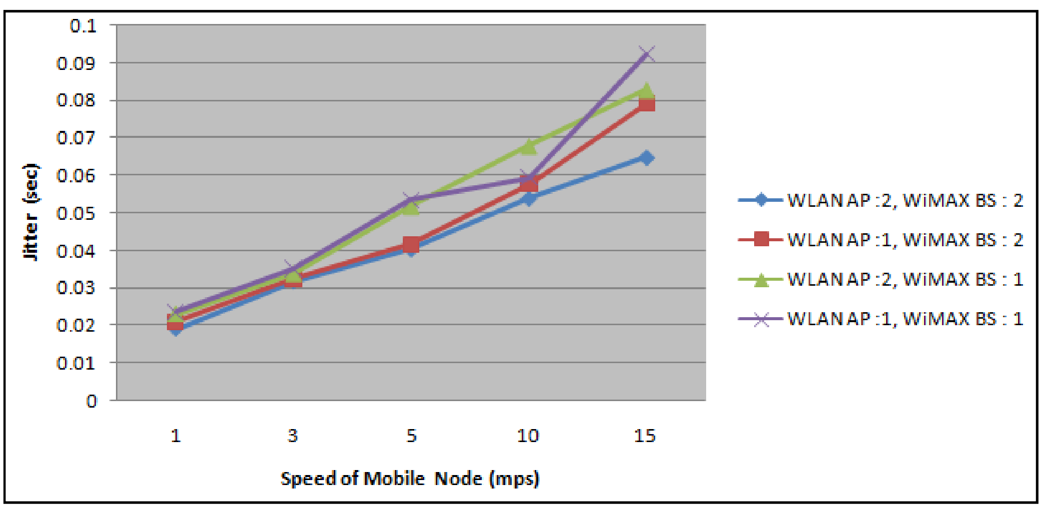

Fig: 5.11 Jitter Response Vs Speed of Mobile Node

In Fig. 5.12 the throughput is analyzed for varying speed 1 mps to 15 mps and number of AP and BS of WLAN and WiMAX respectively.

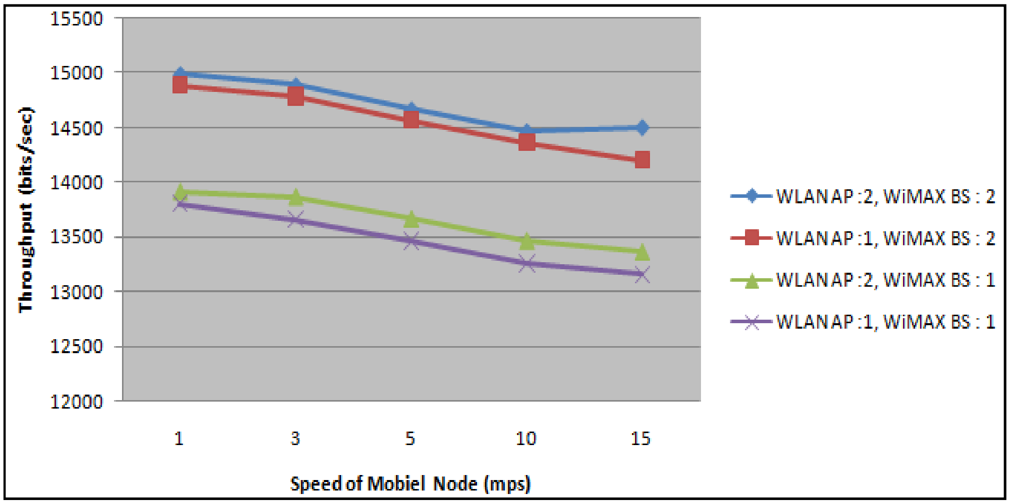

Fig: 5.12 Throughput Response Vs Speed of Mobile Node

It has been observed that throughput is increasing as number of access points and base stations are increased. Throughput is observed minimum at one AP and one BS and maximum for two AP and two BS. This is because as long as number of serving AP or BS increases, the load on serving network decreases. This allows the maximum utilization of bandwidth for mobile node.

In this Chapter proposed OQVHD approach is compared and analyzed for WiMAX-UMTS and WLAN-WiMAX-UMTS networks. In first scenario for WiMAX-UMTS networks QoS parameters delay, jitter and throughput are compared for proposed OQVHD approach with RSA approach. In second scenario the proposed OQVHD approach results are compared and analyzed with RSA approach for WLAN-WiMAX-UMTS networks.

In next Chapter conclusion and future scope of our proposed work has been discussed.

Chapter 6

Conclusion and Future Scope

6.1 Conclusion

In this thesis, a swarm based vertical handoff procedure and decision to achieve QoS is presented for mobile node movement in WLAN-WiMAX, WLAN-UMTS and WiMAX-UMTS networks. For this purpose an interworking architecture of different technologies is proposed and discussed.

In Chapter 3, a new Swarm Based Vertical Handoff Algorithm (SBVAH) is proposed between WLAN and WiMAX. To control and guarantee QoS support, the handoff decision algorithm is combined with ant based routing information. The proposed simulation results show that the proposed SBVAH approach performs well with respect to throughput, end to end delay and jitter. In the first result analysis, the proposed approach is compared for varying load with packet size. It has been found that with respect to increasing load the end to end delay and jitter are increasing. Observing with respect to packet size variation, the end to end delay and jitter have decreasing values, which is better for sending maximum data. In second analysis, the proposed SBVAH is compared with all other approaches. It has been observed that proposed approach is better, for increasing mobile node speed. The end to end delay, jitter and throughput response has been observed and found improved in case of proposed SBVAH approach as compared to Fuzzy Based Vertical Handoff Approach (FBVAH) as well as Ordinary Vertical Handoff (OVAH) approach based on Received signal strength.

In Chapter 4, a new algorithm for vertical handoff in WLAN and UMTS networks is presented. Smart Routing Technique based Vertical Handoff Algorithm (SR-VADH) is proposed and analyzed for WLAN/UMTS scenario. The proposed SR-VADH is compared and found better than fuzzy based approach, data rate based approach and ordinary received signal strength approach. The proposed SR-VADH approach is better with increasing speed of mobile node because as it has smart route connection ability in addition to bandwidth, goodput and battery life monitoring capabilities.

In Chapter-5 a new algorithm for vertical handoff in WiMAX-UMTS and WLAN-WiMAX-UMTS is presented. The velocity adaptive handoff approach with swarm routing technique is used for effective handoff between WiMAX and UMTS. The proposed Optimal and Quality based Vertical Handoff Decision (OQVHD) approach is analyzed for WiMAX- UMTS and WLAN-WiMAX-UMTS scenarios. In WiMAX-UMTS scenario the proposed OQVHD is compared with Route Selection Algorithm (RSA) with varying number of users and speed of mobile node. The proposed OQVHD approach is found better. The OQVHD approach has taken into account all parameters for handoff decision like RSS, load, bandwidth, goodput, velocity with swarm routing technique. The QoS parameters average delay, jitter and throughput are compared for WiMAX-UMTS network. In second scenario the proposed approach is observed and analyzed for three networks integration WLAN-WiMAX-UMTS. The proposed approach is compared with RSA approach with varying mobile speed and data rate. The results show that the proposed OQVHD is better for end to end delay, jitter and throughput. It can be concluded that the proposed work is the result of deep study and analysis of the phenomena involved. Our simulation results reveal that the proposed SBVAH, SR-VADH and OQVAHD approaches perform well with respect to QoS parameters throughput, end to end delay and jitter.

6.2 Future Scope

There are so many issues that would be further investigated in designing the vertical handoff approach for the heterogeneous network. The power consumption is a crucial factor in heterogeneous network. For connection with any network any time, a mobile node in dual interface mode is required to keep itself ON all the time. When the MN is using one interface for communication, the other interface is not being used. The wastage of energy in second interface needs to be prevented at that time. Efficient algorithms which minimize energy consumption are required to be developed to reduce the number of surplus handoff. Further, to provide assured QoS for an open environment in different sectors like agriculture and healthcare, there is a need to integrate more efficient cellular technologies such as long term evolution (LTE), UMTS, and IEEE standard based technologies Wi-Fi (or WLAN) , WiMAX device card and their device driver. The unique features of different technologies can be converted to create an open source platform for professionals, doctors and farmers. With integrated network architecture, users of any profession will be able to improve their work capability as well as their living standard. With use of wireless equipments by drivers and wireless facilities in ambulance, the life saving due to road accident can be improved. Maximum e-health services can be provided to ill and aged persons at their home. Thus in health sector and agriculture sector heterogeneous network environment will be more beneficial.

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