Comparison Of Vertical Handover Decision-Based Techniques In Heterogeneous Networks

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This dissertation is submitted in partial fulfillment of the academic requirements
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Declaration

I hereby declare that: (1) the above dissertation is my own unaided work, both in conception and execution, and that apart from the normal guidance of my supervisor, I have received no assistance apart from that stated below; (2) except as stated below, neither the substance or any part of the dissertation has been submitted in the past, or is being, or is to be submitted for a degree in the University or any other University.

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Abstract

Industry leaders are currently setting out standards for 5G Networks projected for 2020 or even sooner. Future generation networks will be heterogeneous in nature because no single network type is capable of optimally meeting all the rapid changes in customer demands. Heterogeneous networks are typically characterized by some network architecture, base stations of varying transmission power, transmission solutions and the deployment of a mix of technologies (multiple radio access technologies). In heterogeneous networks, the processes involved when a mobile node successfully switches from one radio access technology to the other for the purpose of quality of service continuity is termed vertical handover or vertical handoff. Active calls that get dropped, or cases where there is discontinuity of service experienced by mobile users can be attributed to the phenomenon of delayed handover or an outright case of an unsuccessful handover procedure.

This dissertation analyses the performance of a fuzzy-based VHO algorithm scheme in a Wi-Fi, WiMAX, UMTS and LTE integrated network using the OMNeT++ discrete event simulator. The loose coupling type network architecture is adopted and results of the simulation are analysed and compared for the two major categories of handover basis; multiple and single criteria based handover methods. The key performance indices from the simulations showed better overall throughput, better call dropped rate and shorter handover time duration for the multiple criteria based decision method compared to the single criteria based technique. This work also touches on current trends, challenges in area of seamless handover and initiatives for future Networks (Next Generation Heterogeneous Networks).

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List of Abbreviations

3GPP	3rd Generation Partnership Project
5G	Fifth Generation
ABC	Always Best Connect
AMC	Adaptive Modulation and Coding.
BTS	Base Transceiver Station
CQI	Channel quality indicator
E-UTRAN	Evolved UTRAN
eNB	evolved NodeB
EPS	Evolved Packet System
FIS	Fuzzy Inference System
HetNet	Heterogeneous Network
HHO	Horizontal Handover
I-RAT	Inter Radio Access Technology
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of things
IP	Internet Protocol
KPI	Key Performance Index
LAN	Local Area Network
LTE	Long Terminal Evolution
MADM	Multiple Attribute Decision Making
MSC	Mobile Switching Center
MS/MN	Mobile Switch or Mobile Node
MT	Mobile Terminal

NAI	Network Average Index
PLMN	Public Land Mobile Network
QoS	Quality of service
RAT	Radio Access Technology
RAN	Radio Access Network
RLC	Radio Link Control
ROC	Rank Order Centroid
RRC	Radio Resource Control
RSSI	Relative Signal Strength Indicator
SINR	Signal to Interference and Noise Ratio
UE	User Equipment
UMTS	Universal Mobile Telecommunication Systems
VHDA	Vertical Handover Decision Algorithm
VHO	Vertical Handover
VoIP	Voice Over Internet Protocol
Wi-Fi	Wireless Fidelity
WiMAX	Wireless Interoperability for Microwave Transmission

1 Introduction

Statistics gathered from different sources as reported by the Statista portal shows that there is a staggering growth in mobile users; it is projected that by the year 2017, the number of phone users alone will be pegged at about 2.4 billion [1].

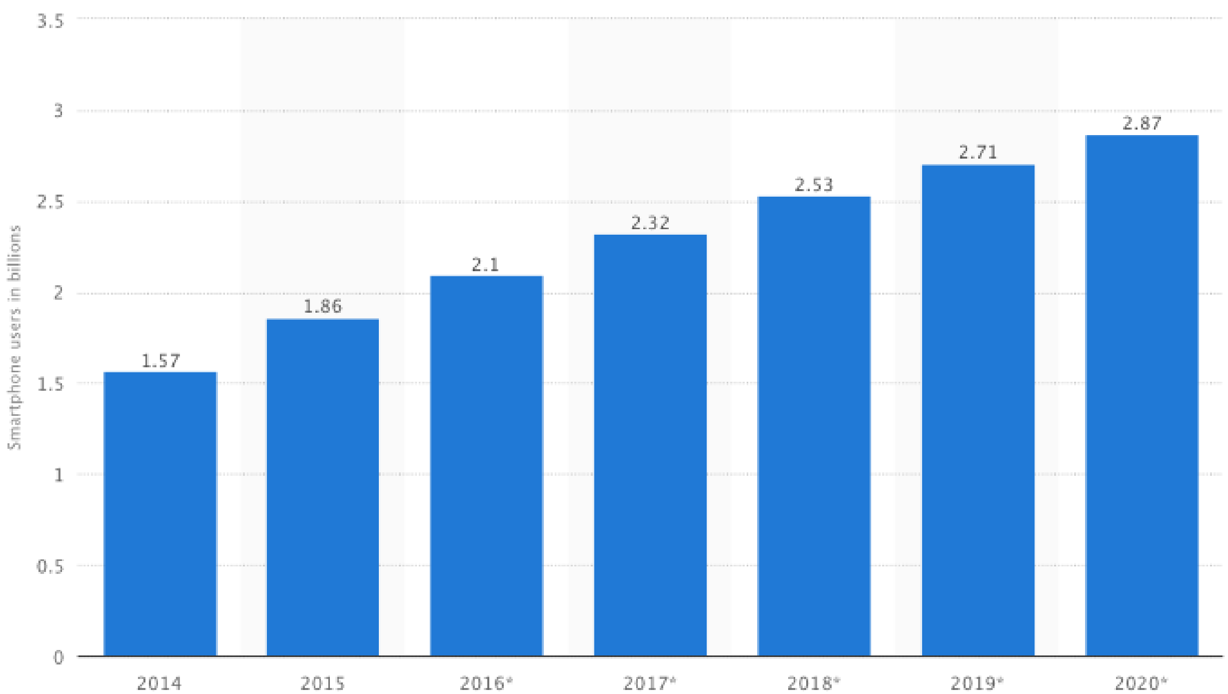

Figure 1. Number of smartphone users in the world (in billions) [1]

A survey from as far back as 2007 emphasized the exponential growth in the deployment of Wireless Interoperability for Microwave Transmission (WiMAX) technology and in the second quarter of 2011 WiMAX technology broke the 20 million global subscriber mark [2]. This directly translates to an increase in the demand for efficient access to network communication services during mobility and thus, there is an urgent need for accelerating and improving technological developments in the areas of wireless access communication. Operators therefore always want to increase network capacity to provide efficient network services to meet this growing demand. This goal may probably be achieved either by technological upgrades to increase spectral efficiency- fifth generation internet of things (5G IOT), via cell splitting / frequency reuse, off-loading data traffic through femto cells or wireless fidelity (Wi-Fi) access points etc. When integrating different access technologies for purposes of improved quality of service, consideration is given to the mobility of the user and the service employed should allow users the choice of radio access technology (RAT) which best suits the required multimedia application (user needs); always best connect (ABC). In the past, existing mobile devices were not equipped to connect to more than one access network simultaneously, they did not support the requirements for multiple RAT's. However, mobile devices are now equipped to physically connect to multiple data links that can be of the same network access technology type or of different access technology types.

With the deployment of heterogeneous networks (different access technologies) and multi-homed devices, an important aspect which has generated a lot of interest both in the industry and academic space is the seamless transfer of active mobile services from one access technology to the other. This network technology then requires the mobile nodes to successfully switch communication session from one radio access network (RAN) technology to another without the user noticing; seamless handover. To achieve this seamless transfer, the IEEE802.21 standard created a framework designed to support all the protocols required for seamless handover process, detecting networks within range and executing the handoff. IEEE provides the framework and the implementation of the actual algorithms is developed by developers, in literature, various algorithms have been proposed by researchers towards this end [3]. This work is interested in the comparison of two categories of handover bases i.e. the single and the multiple criteria based handover with the aim of emphasizing the importance of adopting the most efficient handover technique.

1.1 Motivation

From the evident growth in mobile users as recorded and projected, it is certain that heterogeneous networks (HetNets) will be key in next generation networks (NGN) with various access technology types having individual characteristic advantages [4]. Handover is therefore inevitable and a seamless procedure is desired thus the motivation for handover arises from the evolution of technologies in wireless networks. Also, advantages such as extensive cell coverage, better mobility support, higher bandwidth utilization and lower cost of local area network (LAN) are some of the key reasons why vertical handover (VHO) between different network types attracts lots of research works. With the advent of multimodal mobile devices, switching between different available RAT's from multiple users will be a frequent occurrence thus handover processes will occur simultaneously and frequently. This will occur as the mobility user gains distance from the serving access point or as a result of network congestion. In both cases, with availability of a better network, a good network selection algorithm must be employed to allow for successful handover of multiple users in that area. Various selection algorithms have been proposed and implemented to provide efficient quality of service (QoS) with regards to the users preference and attributes hence the motivation for the comparison aspect of this work.

In recent times, the business world has undergone tremendous transformations as the work force now use computing devices to work away from their desks in various locations. We then are faced with concerns such as the need for higher productivity from the workers, reducing operating cost, customer satisfaction (faster, efficient services) etc. With telecommunication service providers trying to maximize profits and at the same time also provide efficient services to users, we are thus challenged at the highest level to carry out studies aimed at improving/proposing techniques to improve seamless handovers with minimal packet loss and low latency in the HetNet.

1.2 Problem Statement

A mobile user may perceive successful handover as a seamless process since the complexities involved in the process of switching a user equipment node from one cell to another both having the same access technology is considered minimal compared to a handover involving different access technologies. In a heterogeneous network with only one technology type (e.g., UMTS network with femtocell), horizontal handover (HHO) is still possible but it is a lot more complex compared to the traditional cellular network case mentioned above, especially in the transition from a macrocell to a femtocell [5]. The problem addressed is how to reduce packet losses, delay, poor throughput, signaling overhead, which are all attributed to the characteristic handover complexities of HetNets transmissions. VHO will therefore play an important role in future hybrid networks and for this reason studies geared towards selecting the right scheme, enhancing and improving the VHO process and performance are of great interest. Hence we are focused on solving the problems associated with seamless continuity of service either due to network congestion and or movement away from serving access point.

1.3 Research Objective

The seamless transfer of active services for mobile users is desirable and constitutes a major concern in wireless networks. QoS is an important concept that cannot be overlooked and combining it with some network selection process will most likely yield better results. This work compares the performance of multiple criteria decision based handover technique to its counterpart single criteria decision based handover method with the aim of preventing degradation of both real-time services (voice/video) and non-real time services (SMS, MMS and web services) during mobility. In addition to the above, we also hope to achieve the under listed:

I. Present insights in selecting handover schemes and selecting handover design parameters.
II. Provide good QOS to multiple and single users.
III. Create an environment that will adequately simulate the handover scenario and show how easy and powerful the OMNeT++ Framework suits the simulation of communication networks.

To achieve the above outlined objectives, we used fuzzy logic, fuzzy inference system together with a selection process to handle the uncertainties and imprecise criteria focusing on four RAN's; Wi-Fi, WiMAX, UMTS and LTE.

1.4 Scope of Research

This work focuses only on the performance of the single criterion and multiple criteria methods of handover in heterogeneous wireless networks. The single criterion parameter that is investigated in this work is the traditional relative signal strength indicator (RSSI) while the parameters for the multiple criteria used in this work are; RSSI, available bandwidth, cell coverage area and jitter. This work does not propose any novel handover algorithm. Load balancing, mobile IP and admission control will not be considered in this work.

1.5 Research Contributions

This study aims to help the process of adopting the most efficient handover algorithm for heterogeneous networks. Notably, the rank order centroid (ROC) is combined with fuzzy technology technique to assign a terminal to the best network while handover is performed simultaneously. As developed countries gear towards implementation and deployment of 5G in 2020, we must also bear in mind that other developing countries that don't have the infrastructure to support 5G can benefit from this studies as an effective handover scheme selection greatly optimize network performance. In addition to the above, this study will further assist studies geared towards establishing handover index for vertical handover evaluations.

1.6 Dissertation Outline

The rest of the work is organized as follows:

Chapter two presents fundamental principles and concepts of handover. It also discusses related works highlighting techniques adopted in solving the critical issues surrounding handover decision, initiation and execution. The chapter ends with the ratified standards for wireless communication networks.

Chapter 3 is the Design system model and methodology of the dissertation. Here, we give the step by step approach adopted in solving the identified problem. We briefly introduce the key parameters and structures from the developmental stage to conclusion stage.

Chapter 4 discusses the Fuzzy inference system and the procedures involved in obtaining the crisp Fuzzy output value. It discusses all the parameters chosen as key matrices for the system, defining their respective universes of discourse and introduces a MADM method to improve the network selection process.

Chapter 5 further examines characteristics of the adopted networks, underlying working principles and the integration requirements.

Chapter 6 gives a description of the network simulator framework used for the simulation, elaborating on the choice of simulator, its network entities, functions and requirements. This section also displays the outputs, interpretations of the results (KPI's) obtained expressed as charts, graphs and screenshots.

Chapter 7 concludes the dissertation work with setbacks encountered and suggests areas that can be improved on in future works.

2 Literature Review.

In this chapter, we discuss the underlying principles of handover, interesting reviews of handover solutions and background knowledge of the heterogeneous networks adopted in this work. It is concluded with the fundamental ratified wireless standards. Users with devices that support both real-time (video, voice calls) and non-real time services (SMS, MMS) are expected to experience uninterrupted services when switching occurs in a heterogeneous network architecture. Challenges such as availability of bandwidth for each wireless access network, connection charges from service providers, power requirements, device battery status etc. commonly associated with vertical handover have seen significant improvement from the adoption of various handover algorithms. Some of these interesting algorithms are subsequently presented.

2.1 Fundamental Concepts

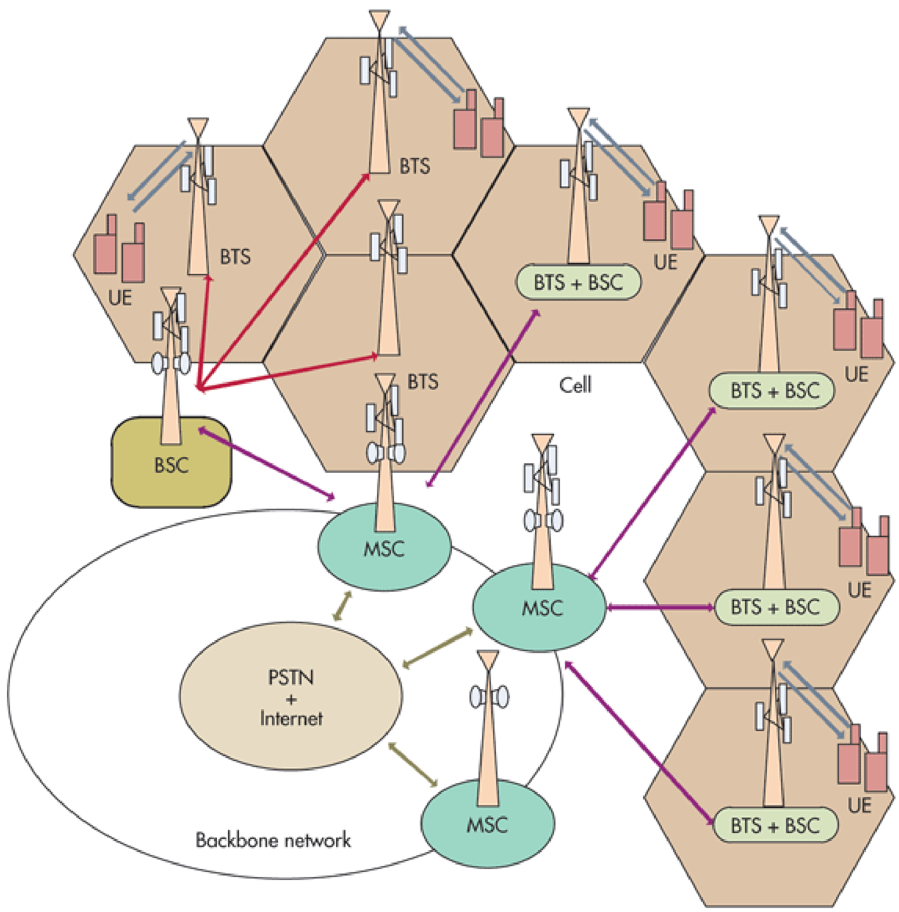

Figure 2.Handover Type Descriptions [6]

Figure 2 above is used to illustrate the different types of handovers. In the diagram, the hexagonal shape panels represent the cell sites coverage area while the connections show MSC's connected to different BSC's and BTS's. A mobile device on an active call which moves from one cell panel to another panel both on the same BTS tower is said to have undergone intra-BTS handover. Inter-BTS handover on the other hand occurs when the mobile device moves from one BTS to another BTS serviced by the same BSC while in a scenario where the mobile device moves to another BTS under a different BSC defines inter-MSC handover. Lastly, external-MSC is when the MSC reaches out to another MSC outside of its own coverage area to request reservation of resources needed for a handover.

Different network operators employ different solutions to service demands from users (voice, text, multimedia) in the market. With all these variations, when a mobile user moves from one location to another, he should be able to maintain connection by the ability to switch automatically and seamlessly to the next best available network technology. Handover or handoff is a term used to characterize the technology which allows uninterrupted continuity of ongoing communication service during mobility. When this mobile connection is switched within the same network, it is called horizontal handoff (HHO). Vertical handover (VHO) also called asymmetric handover refers to the situation where a network node changes between different networks in order to support node mobility [6]. An example can be a laptop equipped to support both a cellular type technology and high speed LAN connection to access the internet. Wireless LAN connections are believed to provide higher speeds while cellular is primarily known for wider coverage areas. The automatic switch of the laptop in the example above from the WLAN to the cellular type technology in order to maintain communication defines the VHO process. Two main internetworking architecture (loose coupling and tight coupling) have been defined for VHO between UMTS & WLAN, according to [7] although there are several possible classifications.

I. Loose Coupling: In a network system design, a loosely coupled system is described as one in which each of the components has little knowledge of the definitions of the other components.
II. Tight Coupling: 3GPP adopted the tight coupling scheme and introduced two more elements. Packet data gateway(PDG) and wireless access gateway(WAG). In tight coupling, all data transfer from the WLAN AP must go through the core network of the UMTS.

Loose coupling is mostly used when WLAN is not operated by cellular operators but by any private user. This is so that the data been transferred through the WLAN or WiMAX will not go through the cellular networks. Some technical factors on which VHO is based on include bandwidth, error rate, battery state, cost, preference for certain radio access technology or certain operators, perceived quality of service among others. The algorithms for network selection process include artificial intelligence methods (neural networks, fuzzy logic), multi criteria decision making (markov, queuing decision processes etc.) or a combination of these methods.

Handover metrics and QoS are key parameters required in the vertical handover decision making process as stated by Y. Xiaohun, et al [4]. In [6], the author defines parameters on which handover will be based on then tests the heterogeneous network performances using different handover algorithms. MEW, TOPISS, SAW and GRA are the handover algorithms implemented in the network using 3GPP traffic classes. The four algorithms must be aware of the relative importance of the defined attributes and this is achieved by a set of weights w_j. The analytic hierarchy process (AHP) is adopted, AHP uses the eigenvector method to determine the weights (w_j) and the fundamental 1-9 AHP scale provides answers to the sequence of comparisons between the set of network parameters. To check consistency in the judgement, a practically accepted consistency ratio indicator CR $\leq$ 0.1 is used [8]. The authors also considered the sensitivity of the assigned weights to the network selection process, where the traffic classes are varied accordingly. The results gotten from the simulation showed that the three algorithms; MEW, SAW and TOPSIS have similar performances to all the four classes of traffic used while GRA showed a slightly higher bandwidth and lower delay for the interactive and background traffic class type.

In a similar fashion, Dhar et al [9] in design and simulation of vertical handover algorithm for vehicular communication also adopted AHP decision technique to establish the network selection process where RSSI with user preferences are the considered criterion used to trigger handover. This novel VHO algorithm was designed for intelligent transportation systems in a multiple constraint environment. Simulation results showed that the presented model optimized the network and avoided unnecessary handovers although it is found to be most suitable for nodes at a certain vehicular speed. It was also observed that all the three networks WLAN, UMTS and WiMAX competed closely until a vehicular speed of 30Km/h is reached. At this speed and greater, the WLAN is unable to support handover despite having RSS value above the defined threshold level.

Sensitivity analysis was also carried out using a mathematical model to justify the design algorithm with priority given to radio access selection.

In [10], the author proposed a low complexity RSSI-based algorithm and then introduces an improved RSSI/goodput version with all operations related to VHO completely carried out by the mobile terminal (MT). The improved version included two matrices; received power and goodput (which coincides with the effective bandwidth) independently available in each link. To arrive at the two metrics, an estimation is carried out periodically at a constant sampling time while two filtering techniques were employed; the weighed moving average (WMA) and exponential smoothing average (ESA). Disappointingly neither the direct nor indirect method of estimation gave a good estimate (indirect method provided insufficient information while direct method was not feasible; not efficient and had economic drawbacks) hence the need for modification. The first modification no longer considered goodput for VHO decision and the second modification assigned RSSI in place of received power. Lastly, the waiting times that occur between consecutive operations due to their inefficiency was eliminated. A test bed was designed to test the VHO algorithm and results showed different behavior of the networks, with UMTS exhibiting almost a constant handover time around its average while the Wi-Fi network performed worse as it had a higher average value.

[11] uses the classical and fuzzy technique approach for seamless mobility across overlaid heterogeneous networks. The authors proposed a neuro-fuzzy multi parameter-based vertical handoff decision algorithm (VHDA), this proposed algorithm uses six parameters and applies database rule set system for VHO decisions. The simulation results of several vertical handoffs showed that the average number of vertical handoffs for the proposed algorithm reduced by 13.3% and 29.8% for the existing fuzzy technique and the classical technique respectively. The results also showed that the Ping-Pong effect reduced by 15.9% while end-point service availability (ESA) and throughput increased by 16.57 and 5.97% respectively. The Neuro-Fuzzy approach was selected because of the advantages of introduction of natural rules on the one hand and the model-free learning on the other hand. Real value data were first converted to Fuzzy representation by defining membership functions, if-then-rules were generated, deffuzification then provided the crisp value output and then training of the Fuzzy system to satisfaction (Neural network).

[12-13] aimed at ensuring workers can move freely across networks while always connected in IP mode. Once again, the fuzzy inference system was used to process a range of criteria for the VHO

decision metrics and a mobility management scheme presented. Syed et al used the Fuzzy logic technique in the evaluation process of the performance of WLAN and UMTS with the two standard integration models proposed by 3GPP. The performance of the network was then analyzed based on FTP and HTTP applications simulated with the OPNET 14.5 modular simulator. The simulation results indicated that the loose coupling type architecture has a smaller response time compared to open coupling scheme for the two application types tested.

In [14], Guo et al presented a fuzzy multiple-objective decision based RAT-selection algorithm for heterogeneous cellular networks. This algorithm selects a RAT for incoming handoff calls where data rate, coverage area, transmission delay, call arrival rate, cell type are defined as the key matrices for the RAT-selection. To further select the optimal cell from all candidate networks, a fuzzy multiple objective decision is then applied. [15] proposed an intelligent decision algorithm which decides if a new network will offer better connectivity than the current serving network. The algorithm used is also responsible for authentication/mobile IP registration which reduced the probability of packet loss thus ensured optimum quality of service. This algorithm showed a maintenance in load balancing and traffic engineering by forwarding of data packets to the right attachment point which in turn maximized the battery lifetime of equipment. The proposed algorithm efficiently employed network resources by alternating between the 3G and Wi-Fi networks under different RF environmental conditions at negligible additional service cost to the users. They stated that the proposed algorithm reduced the call dropping rate and call blocking probability by less than 0.006 and less than 0.00607 respectively. The unnecessary handover in the heterogeneous network (ping pong effect) was also reduced significantly. In [16], the author describes various VHO models together with the parameters they considered necessary for handover. All empirical weighting factors, multiple attribute decision making (MADM) model, policy-based decision model and server-based decision models were then compared. An interesting survey was carried out by E. S. Swami and E. S. Soni in handover decision approaches in heterogeneous wireless networks using fuzzy logic system [17], a survey which reviewed recent works done on vertical handover implementation for the classical and traditional approaches for heterogeneous networks. The Fuzzy handover technique showed superior performance from the comparison of the individual index of the different methods studied.

2.2 Background Knowledge

In 2G telecommunication systems, the global system of mobile communication (GSM) was known to be the largest technology [18]. It allowed for voice traffic between node terminals wirelessly throughout the communication network. However, this technology was limited due to the demands for on the move multimedia services hence the development of Universal Mobile Telecommunication System (UMTS). Universal terrestrial radio access network (UTRAN) is the radio access network for UMTS, it is responsible for data, radio resources and signaling for traffic exchange between the core network and the user equipment. It handles allocation of requirements for traffic support and is based on WCDMA. UMTS is Classified as 3G system of mobile communication, it was designed to support up to 1Gb of data rate and support various combinations of access technologies. A wireless technology system designed to deliver low cost and high capacity mobile communication. The UMTS is based on GSM network standards and comprises of three major components; the core network, user equipment and the radio network. The core network further comprises of the circuit switched network and packet switched network that cater for services such as voice calls and email traffic respectively. Media gateways (MGW's) route the phone calls while the handling of signal messages for set up and tearing down of sessions is carried out by the mobile switching center (MSC) in the CS domain. On the other hand, the PS domain, the gateway GPRS support node (GGSN) serves as the interface link between the outside world packet data network and the server. Serving GPRS support node (SGSN) is responsible for the routing of data between the GGSN and the base station while the information of the network operator's subscribers is housed in the home subscriber server (HSS) database. The most important network element in the UMTS radio network is the NodeB which is usually equipped with several antennas to communicate with the user equipment (UE) in each sector. Sector here refers to the cell (micro, pico and femto), its size limited to the maximum range where the receiver can hear the transmitter successfully. The radio access in a nutshell handles all the radio communications between the various users and the core of the network, GSM edge radio access network (GERAN) and the universal terrestrial radio access network (UTRAN) make up the radio access network. The radio network controller as the name implies controls signaling messaging of mobile radios and basically groups the base stations together. Frequency division duplex (FDD) and time division duplex (TDD) are the common access technologies employed to forestall interference during transmissions, the base station transmits on different frequencies in the case of FDD and transmits on same frequencies but at different times in the case of TDD. Finally, the user equipment engages in the communication process with the core network via the air interface. When this communication is from the user equipment to the core, it is referred to as upload link and when communication is in the reverse direction, it is termed download link.

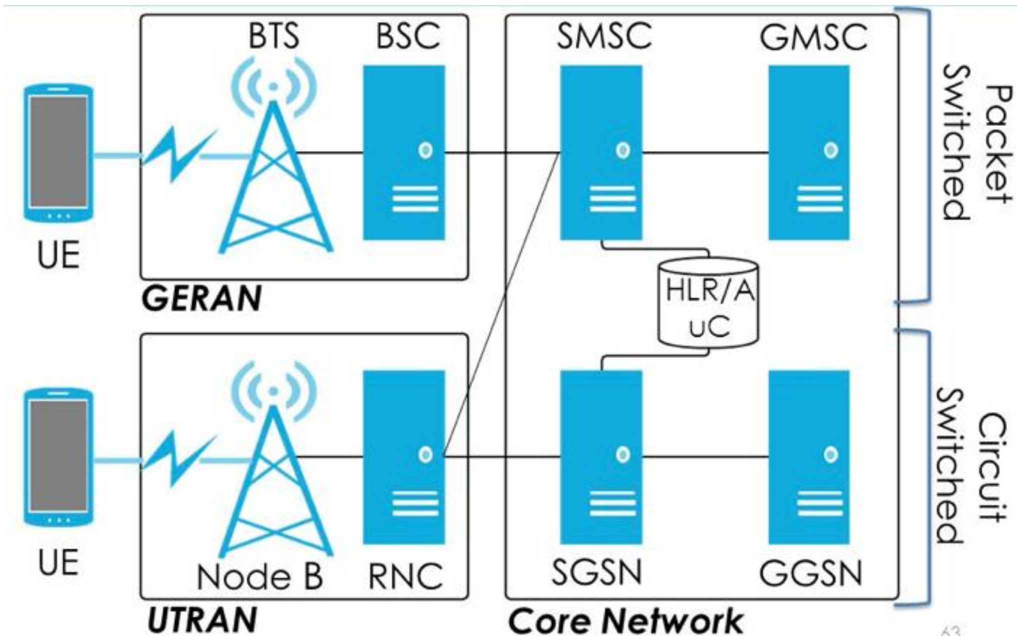

Figure 3.UMTS and GSM high level Architecture [18]

In recent times, Wi-Fi has become the preferred connection method to the internet for various reasons. Network traffic is broadcasted over radio waves hence the term wireless (needs no cable connectivity), in most cases this is achieved by a central device called a router, a high speed internet modem and a network hub or switch. Wireless fidelity commonly called WLAN allows wirelessly enabled devices connect to broadband in a wireless mode as earlier mentioned, these wireless devices are equipped with an installed Wi-Fi card or an external Wi-Fi adapter [19-20]. The IEEE 802.11 is the international standard describing characteristics for wireless communications via electromagnetic waves. The different wireless protocols are 802.11a, 802.11b, 802.11g and 802.11n with the first two types now legacy generations of protocols. The lower layers in the OSI model are the key players in Wi-Fi network, i.e. the data link layer (logical link control and media access control) and the physical layer. Modulation techniques are defined at the physical layer and the data link layer defines interface connection between the physical layer and bus of the machine. Wi-Fi works as a two-way traffic as data to be passed through the internet passes through a router to be coded into radio signals then same data is received by the device's wireless adaptor and vice-versa.

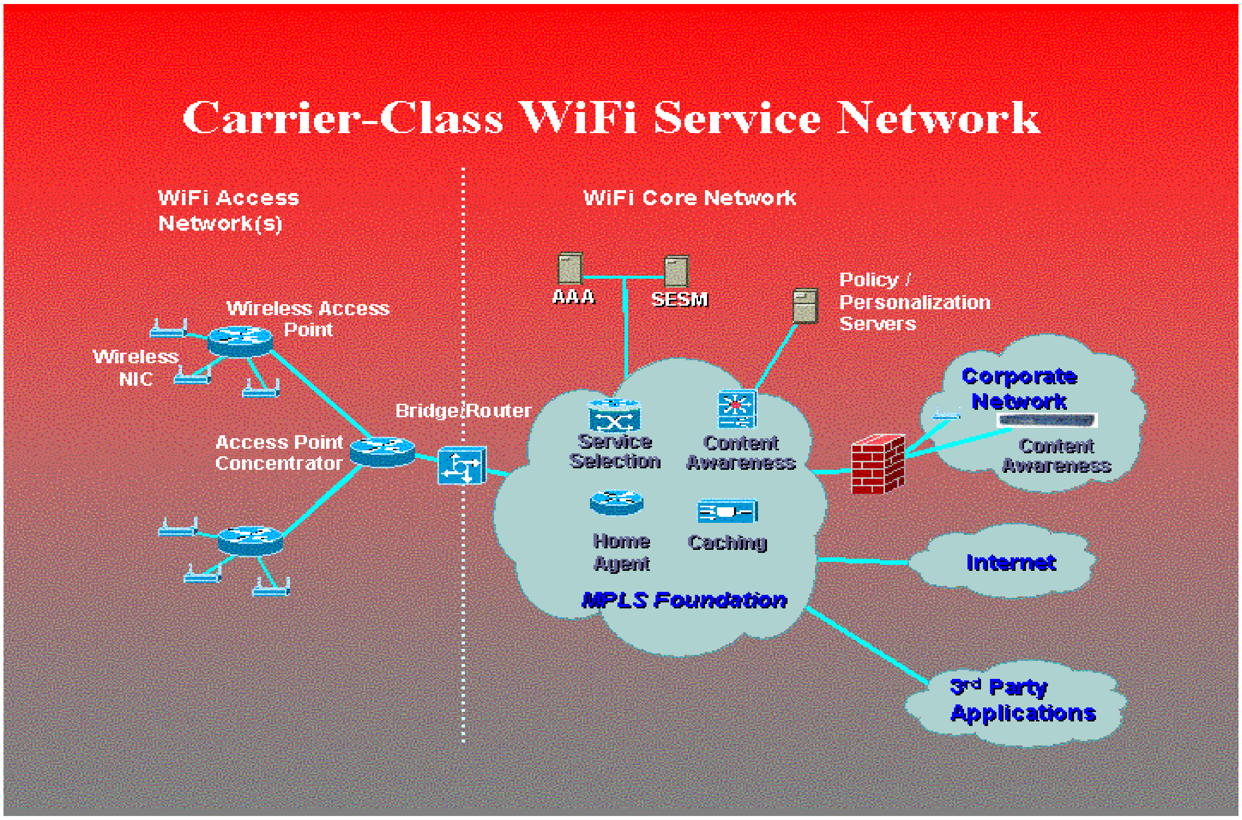

Figure 4.Wi-Fi Network description [19]

Worldwide interoperability for microwave access (WiMAX) supports mobility to the user by its fast speed and wider coverage area compared to Wi-Fi. WiMAX is also popular for its relatively cheap cost of deployment. It is an attractive metropolitan access technology suitable for rural and metropolitan area broadband wireless access, it supports large range of applications (enterprise and residential environments) and literature has it that for a single WiMAX cell the average coverage area is between 30-50Km [20]. The WiMAX architecture comprises of base station (BS) which provides the air interface to the MS. It is responsible for providing additional functions such as tunneling, triggering handoff, tunnel establishment, traffic classification, radio resource management, QoS policy enforcement, Dynamic Host Control Protocol proxy, key management, session management, and multicast group management. The access service network gateway (ASN-GW) basically serves as a layer 2 traffic aggregation point. Other functions of the ASN gateway include paging, AAA client functionality, admission control, radio resource management, intra-ASN location management, caching of subscriber profiles, establishment and management of mobility tunnel with base stations, QoS and policy enforcement. Connectivity service network (CSN) is responsible for the provision of connectivity to other public networks, cooperate networks, the internet and APA.

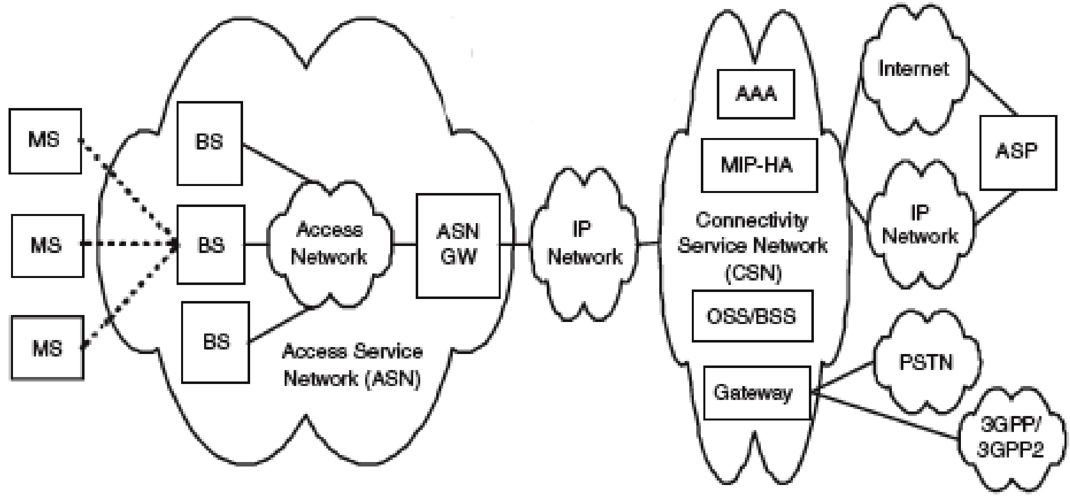

Figure 5.WiMAX Network Architecture [20]

The 3rd Generation Partnership project (3GPP) developed the Long-Term Evolution (LTE). LTE and SAE (System architecture Evolution) make up the Evolved Packet System (EPS), an evolution of the UMTS architecture. The LTE enables higher data throughputs to mobile terminals to support advanced and new mobile broadband services. It supports only packet-switched services with the aim of providing seamless IP connectivity between the packet data network (PDN) and user equipment (UE) for service continuity during user mobility [21-22]. The three major parts of the LTE network include the core network (CN) which is also referred to as the EPC. This network element comprises of other network elements such as the PDN gateway, the home subscriber server (HSS), serving gateways (S-GWs) and the mobility management entity (MME). The second major part of the LTE is the radio access network (RAN), it contains the controlling units together with their corresponding number of base stations (eNodeB) connected to the core network [23]. All the eNodeB's are connected to one or a more SGW/MME with each eNodeB connected to one or more MMEs/S-GWs with the S1 interface. The third network equipment is the user equipment (UE) or mobile terminal (MT). This component includes a universal subscriber identity module (USIM) which is issued by the operators and is used to store security related information for subscriber identification. Authentication, paging, mobility, managing session states are events managed by the mobility management entity (MME) while storage and management of all subscriber information such as QOS of different bearers, restriction and roaming take place at the home subscriber server (HSS). Functions such as assignment of IP addresses to UEs, per-user packet filtering, QoS enforcement for guaranteed bit rate (GBR) bearers are performed by the PDN gateway. This simply implies that management of all that happens when the mobile device moves between two or more different technologies is performed by the PDN gateway. The visits policy control and changing rules functions (PCRF) is a software component operating at the PGWs. This caters for policy control and decision making together with controlling the flow-based charging functionalities. The Serving Gateway (S-GW) on the other hand serves as a local Mobility anchor point for inter-eNodeB handover, it also performs functions such as collecting information for charging in the visiting network (e.g. user data volume received or sent). The S-GW also acts as a mobility anchor for mobility within 3GPP technologies such as LTE and UMTS [4]. Some known characteristics of LTE include its support for variable spectrums that can be used with 1.25MHz, 2.5MHz, 5MHz, 10MHz, 15MHz and 20MHz. In literature, LTE is said to supports 300 Mbit/s downlink data rates when Multiple Input and Multiple Output [MIMO] antenna technology is employed and has power saving protocols (DRX and DTX) [23]. The LTE single cell is known to cover up to 100 km area with little degradation of service after 30 km. With the 5MHz spectrum, LTE can reach 200 users per cell. LTE increases service provisioning with its more services at lower cost and better user experience capabilities, it utilizes IP, reduces latency, increases cell edge bit rate at the same time maintaining same site locations as deployed today [22].

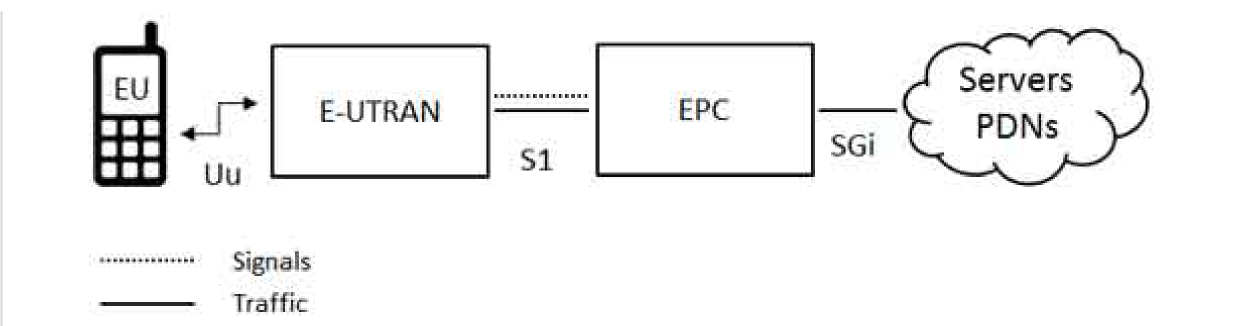

Figure 6.Simplified LTE Architecture [20]

About six different internetworking scenarios have been defined by 3GPP; 3G based access control and charging, Access to 3G packet switched services, common billing and customer care, access to 3G packet switched-based services with service continuity, access to 3G circuit switched-based service with seamless mobility and access to 3G packet switched-based services with seamless service continuity. The mentioned architecture can be reduced to about four and these are defined as listed [24, 25, 26].

I. Open Coupling
II. Loose Coupling
III. Tight Coupling
IV. Very tight Coupling

As earlier mentioned, for the integration of WLAN into cellular networks, there are two main models defined in literature; loose coupling and tight coupling. These models represent the current R & D to achieve global mobility management [23-24]. Our simulation process will be carried out in the loose coupling architecture; a scenario where the networks interconnect independently, provide different services but utilize one common subscription (Billing and AAA). The interworking point for the different networks in this type of architecture starts after the interface point of the gateway GPRS Node (GGSN) with the IP network and the mechanism for this interconnection is the mobile IP (MIP). The UMTS AAA server is actually the point of connection between the access networks with no direct link to the 3G network equipment. In essence, data traffic does not pass through the UMTS core network but rather through the internet (Wi-Fi-UMTS). A periodic transmission by the cellular UMTS base station advertises the outgoing mobile node to the WLAN network, when this advertisement is detected by the mobile node, it then examines the RSS in order to make the handover decision. The mobile node first establishes an estimate of the RSSI from the access router of the WLAN and compares it to that of the UMTS network. Whenever this value gets greater than that of the UMTS then a handover process is initiated otherwise it maintains connection to the UMTS network. The RSS of the UMTS network is expected to get weaker as the mobile node approaches the access point of the WLAN and as the MN gets to the overlap area of the two networks, it informs the CN followed by a transmit registration request to access the router of the other network. A reverse procedure occurs when the mobile node travels in the opposite direction.

As stated earlier, chapter three; the design section, the wireless nodes are modelled in the simple model using the OMNeT++ event simulator. This model does not provide the higher layer protocols found in the advanced model. The simple model has only the physical and multiple access control (MAC) layer which reduces the complexity of our simulations. The NIC and MAC type used in this work are Nic80211p.mac1609_4 : Mac1609_4 and it primarily manages timeslots for CCH and SCH listening and sending processes. The detailed network parameters employed are further discussed in chapter six section below.

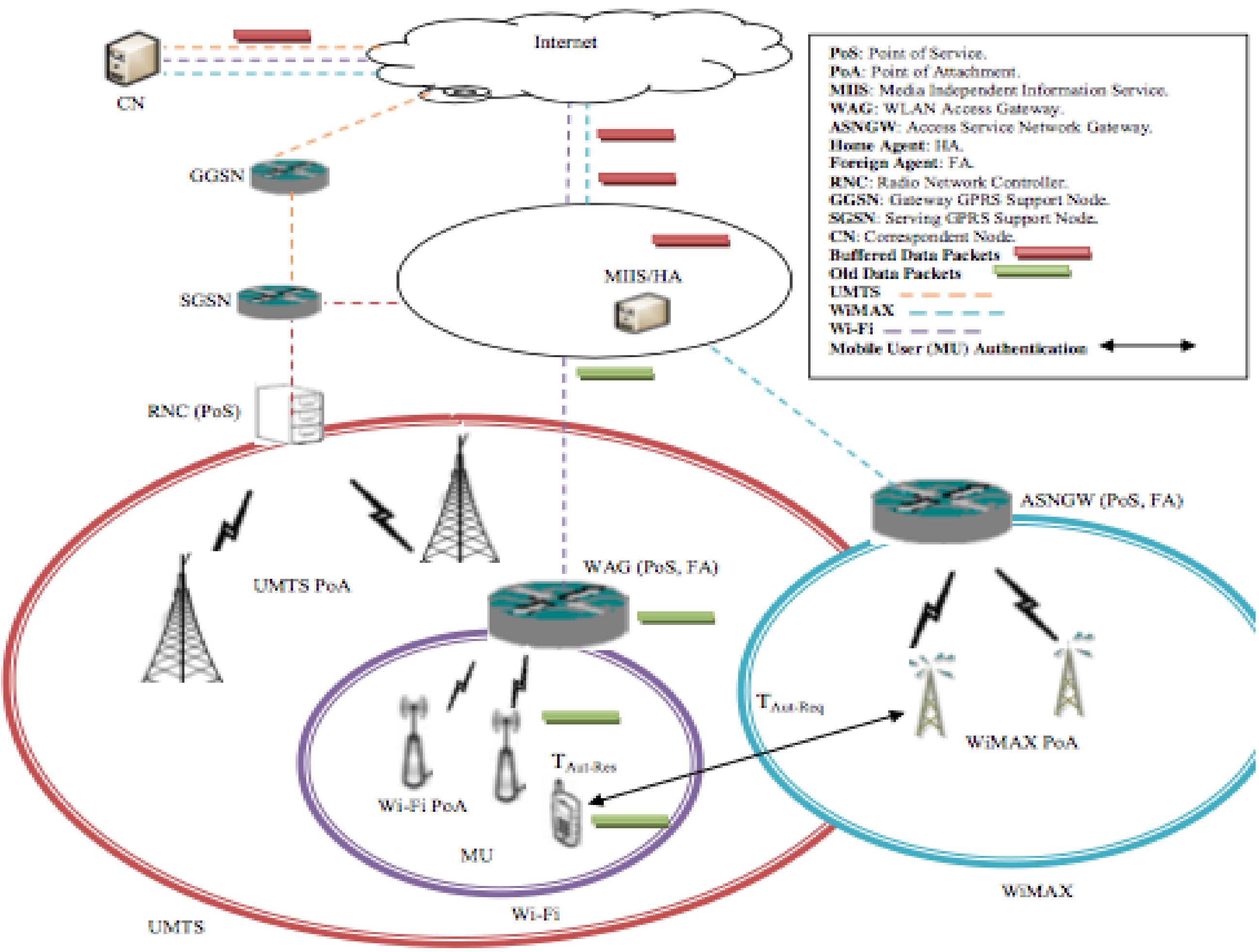

Figure 7.HetNet depicting physical range of wireless networks interconnection [21]

A combination of various technologies will be employed to cater for the different services needed by mobile users in Next generation networks. These different type RATs have different capabilities such as different supported data rates, cell coverage area, cost, etc. [27]. For example, UMTS provides high coverage area, high cost and low data rate from 144 Kbps to 2 Mbps at 10 Km/h to maximum 500 Km/h depending on propagation channel, while the Wi-Fi provides low coverage area, low cost and high data rate from 1 Mbps to 54 Mbps at 30 m to maximum 450 m [28]. UMTS and Wi-Fi have characteristics that complement one another. WLAN provides high data rates at a relatively lower cost but with limited coverage area while UMTS is known to provide a wider coverage area, full mobility and roaming but offers low bandwidth connectivity for traffic. No one Network access can solely provide low latency, low power consumption and high bandwidth to a large number of users thus integration of various access technologies can help achieve higher desired service capabilities. Thus internetworks are meant to provide better QoS, best data rates, increased coverage area, always best connect, extensive mobility support, IP based traffic and other functionalities among different networks. From the operators' point of view, the integration of different access technologies will provide efficient use of the network resources as each different network provides a different level of bandwidth, coverage area, QoS with regard to mobility and cost to the mobile user.

2.3 The Need for Handover

Asides the main reason which is maintaining communication during mobility, there are several other factors which require a need for a successful handover process. This includes factors like the inconsistency associated with wireless physical medium (e.g. obstacles blocking the waves), dynamic decisions of other mobile devices, periodic change in the applications running on the node thus requiring a corresponding change in network parameters. We must also recognize that in reality, due to the unpredictability of wirelesses network environment, QOS is far from constant. Therefore, the solution to all these in addition to availability of efficient networks is a seamless handover procedure, i.e. the process unnoticed by the user. There is the need for mobile devices to be able to choose the network which offers the best quality of service as they transit the network coverage areas at different speeds.

2.4 Handover Stages

The handover management process can be defined in three states or phases, i.e. the journey from its inception to its successful execution;

- Identifying the networks that are within range of the device. This is done by scanning and is termed Network discovery or handover information gathering and it is the first step in the HO process.

- Making a choice from the various networks. This can be done by either the terminal or the network. Studies have shown that the selection is usually one although more networks can be selected if there exist a multimodal terminal. Network selection also termed handover decision is the second step in HO process i.e. whether and how HO is performed.

- Lastly, the actual handover – i.e. carrying out the action of switching the data session from one network to the other. This is dependent on the HO algorithm/standards chosen and is also termed handover execution. This phase can also be further classified based on the manner in which it is executed. When the mobile terminal (MT) is connected to only one point of attachment at a time, it is termed hard handover better described as break before make. i.e. the node discontinues connectivity with the initial serving base station (BS) before connecting to the new BS. On the other hand, soft handover also described as make before break is when the MT is connected to two points of attachment simultaneously for some time interval. This means that the transfer from one access technology to the other is unnoticed to the user when a soft handover process is employed during the execution phase.

2.5 Handover Solutions and Protocols

Irrespective of the type of handover, handovers can be further classified depending on where the handover operations take place. Network-controlled, mobile-assisted and mobile controlled [29].

- Network controlled handoff (NCHO)- The decision for handoff is made based on the measurements of the MSs at several BSs and this decision is made by the network. Qing-Zeng and Dharama P Agrawal in handoff in wireless mobile networks explained that the network switching, data transmission and channel switching which are the handoff processes takes about 100-200ms [10] and the information about the signal quality of all users is available at a single point in the network. Total access communication system (TACS), advanced mobile phone system NMT and AMPS (analogue systems) are first generation networks that employ NCHO.
- Mobile assisted Handoff- In this process, the mobile switch (MS) does the measurements while the network makes the decisions based on these measurements. The BSC oversees the radio interface management. (allocates and releases radio channels, handoff management).

- Mobile controlled handoff- In this case, each MS oversees the HO process. Signal strengths from surrounding BSs and interference levels on all channels are measured by the MS and a handoff is initiated once the strength of another BS is greater than a preset threshold of the serving BS.

According to [30], mobile IP is most popular among the handover management solutions. This is an IP layer mobility management protocol which redirects packets sent by a correspondent node (CN) to a MT in its current location. Mobility agents, home agent (HA) and foreign agent (FA) are introduced here and the handover procedure is summarized in the two steps listed below.

I. The MT detects whether it has moved to a new location by sending messages to or from the mobility agents. This is called agent discovery.

II. MT then obtains a temporary new address, care-of-address (CoA) when it enters a new access network. The new CoA is registered with the home agent which sets up a new tunnel up to the end point of the new CoA and removes the tunnel to the old CoA (registration) as such, routing and tunnelling can commence successfully.

Handover may occur at any layer on the IP protocol stack and each layer has its own unique handover characteristics [31].

Link Layer L2TP, RARP, PPP, OSPF, PPP, ARP,(Ethernet ISDN, DSL)	Only link layer operations are used in changing points of attachment.
Internet Layer IPv4, ICMP, ICMPv6, IPv6, IPsec	Irrespective of the mobile devices movement, handover at the internet layer provide transparency.
Transport Layer	This was introduced to cater for the shortcomings with the Mobile IP methodology. E.g. network security, inefficient routing etc.[44]

Application Layer UDP, TCP, DCCP, RSVP,SCTP	Handover is performed in the end-end session without the intervention of any intermediate network agent, it is not categorized as vertical or horizontal. [17]

2.6 Handover Criteria and Decision Policies

Handover criteria are the qualities which are taken into consideration or measured with the aim of indicating whether or not a handover is needed. The below is a grouping of different criteria selections:

- Terminal related- This will comprise of factors such as battery power, location information, velocity etc.
- User related based algorithms- The algorithm takes into consideration the user profile, user preferences such as choice of network, cost, QoS requirements. Ormond et al explains that the user based function analyses user satisfaction by using utility functions for non-real time data services [29,31]
- Service related based algorithm- includes service capabilities, QOS, residual bandwidth etc.
- Parameter aggregation algorithms- In [32], the author used a model based on TOPSIS, GRA and SAW and comparisons were on the basis of characteristics such as delay, jitter BER and the results showed that the algorithms depended on the importance of the weights assigned to each parameter.
- Mathematical algorithms- Algorithms based on decision processes such as the Markov decision. Stevens et al explained further that a link reward function is defined based on the applications QoS requirements, signalling cost function associated with latency and this algorithm was tested with data and voice traffic. [6]
- Network related- Coverage, bandwidth, latency, received signal strength (RSS), carrier to interference ratio (CIR) security level, monetary cost etc. make up this category.

- RSS – Where MT continuously measure RSS. In [33], Zaharan and Liang worked on combining RSS measurements as proposed for handover between WLAN and 3G networks where the continuous calculation of the RSS average using the moving average method was employed.

Depending on the frequency and causes criteria changes, the criteria selections can be further sub grouped under static or dynamic. Parameters such as cost of individual networks and user profile are seen as static criteria whereas the MTs velocity and RSS are typically considered dynamic criteria. These decision criteria help in the determination of the access network to be chosen, and the handover decision policy; when and where the HO should occur.

- RSS: choosing the new Base Station (BS) if $RSS_{new} > RSS_{old}$.
- RSS with Threshold T: choosing the new BS if $RSS_{new} > RSS_{old}$ and $RSS_{old} < T$.
- RSS with Hysteresis H: choosing the new BS if $RSS_{new} > RSS_{old} + H$.
- RSS, Hysteresis and Threshold: choosing the new BS if $RSS_{new} > RSS_{old} + H$ and $RSS_{old} < T$.
- HO Algorithm with dweller timer: When starting the Dweller timer, the condition is true and HO is performed if the condition continues to be true until the timer expires.

However, in HetNet, other parameters such as offered services, monetary cost, network conditions, user preferences must be evaluated for vertical handover decision policy. More criteria are needed not only for the terminal capabilities decision of the appropriate time to perform the handover but also for user choice and intervention (user preferences among different access technologies) [24]. In the advent of a combination of all these criteria, we expect complexity in the VHO process due to their dynamicity.

2.6.1 VHO Decision algorithms

Handover processes are usually based on algorithms, the decision to initiate a handover is based on different measurement results sent form the mobile switch (MS) or base transmission station (BTS) i.e. parameters which have been set for each cell and algorithms. Depending on the type of situation, different algorithms are implemented to ensure successful handovers. A lot of algorithms have been proposed and implemented and a few are as enumerated below:

- Signal strength based hard handover algorithm
- Velocity adaptive handover algorithm
- Pilot-to-interference based handover algorithms

The VHO procedure includes events such as association, reassociation, registration and dissociation. In UMTS network, the mobile nodes will continuously monitor for higher data rate services of WLAN availability. As mentioned above, algorithms are implemented in a mobile station to make decisions. Simply put, they can be defined as handoff decision engines.

2.7 Standards

The accuracy of the handover simulation also depends on the standards. Standards ensure that all the relevant scenarios are considered. This section takes a brief look at the standards applicable to the access technologies LTE, Wi-Fi, UMTS and WiMAX to ensure a transparent handover at the network level. Standards also make replicating simulation scenarios easier to implement physically and vice versa, the G1010 recommendations provides details on specific value parameters required for different network applications to ensure good QoS.

2.7.1 Wireless Data Transport Standards

IEEE family of standards includes standards for the wireless metropolitan area network (WMANs), wireless local area network (WLAN), IEEE 802.16 and IEEE 802.11 respectively. Other standards for Ethernet, Bluetooth/ZigBee wireless private area networks exist but are not discussed in this work.

Wi-Fi 802.11- The general characteristics can be as summarized as follows. First, the noticeable significant differences in the physical layer between wired network and 802.11 WLANs e.g. its lack of boundaries in the medium. Also, the limit after which frames can no longer be received is unknown [34]; i.e. the handover may be executed long before the MT exits the network. Some concerns of the wireless include; it is less reliable, asymmetrical, susceptible to signal interference so an increase in the number of users does not only bother on throughput but also makes exchange of information more difficult and hinders full connectivity. Security is also a concern as critical packets require encryption. With these characteristics, QOS cannot be guaranteed. Some of its advantages are it allows devices to move freely and still have connectivity, the network fits in most environments, it is easily deployable, low cost etc. WLAN provides all the benefits and features of traditional LAN technologies without the limitations of wires and cables. IEEE 802.11 standards include: 802.11a-54Mbps Standard, 5GHz signalling, 802.11b, 11Mbps standard , 2.5GHz signalling, 802.11c-Operation of bridge connections, 802.11d-worldwide compliance with regulations for use of wireless signal spectrum, 802.11e-Quality of service support, 802.11f-Inter-Access point protocol (IAPP), 802.11g-54Mbps standard, 2.4 GHz signalling, 802.11h-Enhanced version of 802.11a to support European regulatory requirements, 802.11i-Security improvements, 802.11j-Enhancements for the 802.11 family, 802.11k-WLAN system management, 802.11m-Maintenance of 802.11 family documentation , 802.11n-100+Mbps standard [35].

IEEE802.16 WiMAX- is a broadband wireless access technology that ranges in kilometres and tens of Mbits/s with a theoretical data rate of 70Mbps. From the WiMAX specifications, the operational frequency is placed between 10-66GHz and adopts Orthogonal frequency division multiplexing as its modulation scheme. Scalable orthogonal frequency division multiple access (SOFTMA) was introduced in mobile WiMAX (802.16e) and the support for multiple antenna is through the adoption of multiple input output (MIMO). Wi-Fi and WiMAX are usually compared considering the fact that they belong to the same wireless technology standards (802). Wi-Fi and WiMAX differ in range, WiMAX uses licenced spectrum while WLAN is unlicensed. There is also a difference in their quality of service mechanisms, WiMAX uses scheduling to reserve channels in order to guarantee quality of service. This basically rates WiMAX as more bandwidth efficient and stable compared to Wi-Fi. Quality of service in WLAN is relative because of packet priorities and use of contention. However, a limitation of WiMAX is that at the distances specified, the bit error rate increases hence a lower bit error rate must be used. Mobile WiMAX is said to have lower throughput because of its Omni-directional antenna, the available bandwidth is shared among users in a radio sector thus possibilities of poor performance as number of users increase. Standards include [24]; 802.16a-works in 2-11GHz range and supports mesh deployments, 802.16b-increases amount of spectrum that can be used in 5 and 6GHz range QOS, 802.16C-works in higher frequency range of 10 to 66GHz, 802.16d-improvements to 802.16a, deals with wireless connectivity between fixed devices, 802.16e-supports mobile devices(laptops, PDA'S Phones), 802.16f-works on incorporating mesh networking capabilities.

Table 1. Wireless Connectivity Standard

Name	IEEE Standard	Frequency Band	Data Rate
WLAN	IEEE 802.11a IEEE 802.11b IEEE 802.11g IEEE 802.11n IEEE802.11ac IEEE 801.11af IEEE 802.11ah IEEE801.11ad	5GHz 2.4GHz 2.4GHz 2.4GHz,2.5GHz 5GHz 54-790MHz < 1GHz 60GHz	54Mbps 1Mbps 54Mbps 600Mbps 6.93Mbps 26.7Mbps for 6/7-MHz 35.6Mbps for 8MHz 7Gbps
Bluetooth		2.4GHz	1-3Mbps
Zigbee		2.4GHz(worldwide) 915MHz(USA) 868MHz(Europe)	20-250kbps
LoRaWAN		915MHz(USA) 868MHz(Europe)	0.3-50kbps
Z-Wave		908.42MHz(US) 868.42MHz(Europe)	Up to 100kbps
THREAD		2.4GHz	250kbps
SIGFOX		915MHz	Very low
NFC		13.56MHz	424kbps
WirelessHART		2.4GHz	250kbps
Weightless		<1GHz	Up to 10Mbps
LTE Cat-1		Cellular bands	Up to 10Mbps
LTE Cat0/LTE-M		Cellular bands	Up to 1Mbps
Narrowband IOT		Cellular bands	Tens of kbps

Global system for mobile communications (GSM), Enhanced data rate for GSM Evolution (EDGE), General packet radio service (GPRS), Code division multiple access (CDMA) and Universal mobile telecommunications systems (UMTS) are some identified technologies that are defined in the cellular networks. Cellular networks generally comprise of radio cells and a number of transceivers, have defined coverage areas, mechanisms such as frequency division multiple access (FDMA) and code division multiple access (CDMA) for identifying signals from different transceivers.

To fully write out the entire specifications for LTE, a 4^{th} generation mobile network technology will consist of volumes of pages, most of its characteristics have been discussed above and a few more will be highlighted in chapter 5. The exponential growth in mobile subscribers data usage has been one of the main motivations for deployment of this technology. Most of the many features and cellular concepts of LTE are improvements from legacy 3G cellular technologies (with new sets of features and concepts). E.g. CDMA employed in 3G systems replaced by OFDMA as the downlink multiple access method which is also very compatible with the MIMO technique. Key features of LTE include; Enhanced air interface concepts, lower latencies and higher data rates, efficiency (cost of operation), backward compatibility with legacy 3GPP systems, frequency flexibility (about 17 paired and 8 unpaired bands) and various literatures reports its good spectral efficiency among other features.

3 Design Model and Methodology

This section brings to light the awareness of the problem and how we approached it, the circumscription, knowledge and goal operations involves the importance of understanding the problem. In our case, we identified the problem of poor quality of service (QoS) and quality of experience (QoE) which we directly attribute to the type of handover mechanism implemented in a heterogeneous Network. The figure below shows a general design cycle, one of the popular design research methods as described by Vaishnavi. V et al [36]. This design model is the approach employed in this dissertation work.

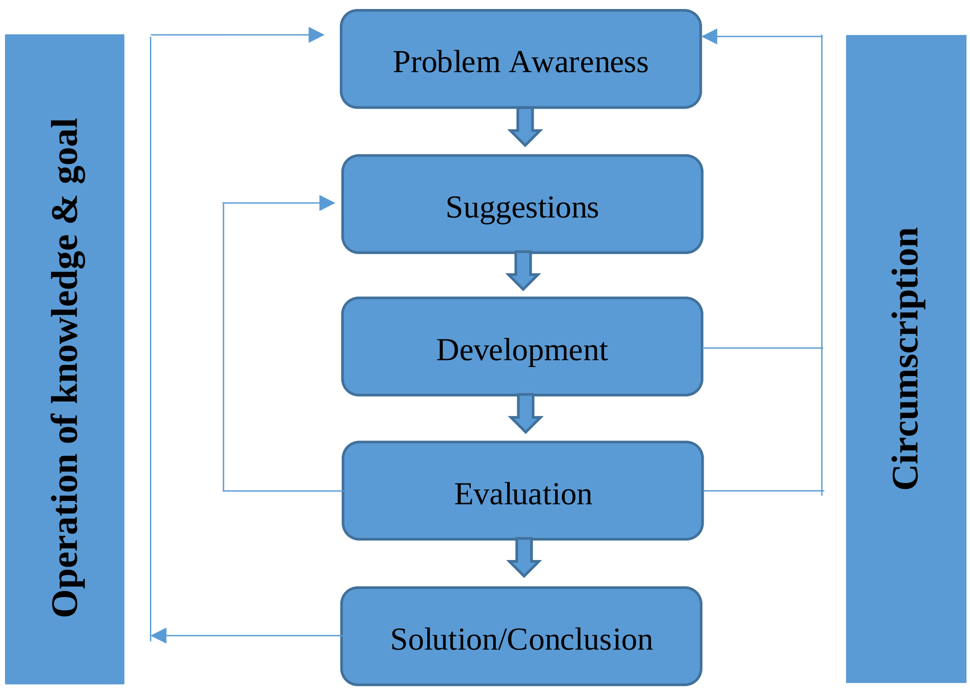

Figure 8.Design Cycle

In chapter two above, we reviewed some of the handover techniques proposed and or implemented by different authors in solving similar problems. These techniques range from novel ideas or a combination of methods applied to solve the issue being addressed From the works reviewed, we adopted a combination of existing technique and approach to arrive at the desired results (MADM and a weighing technique).We use the Fuzzy based handover selection technique together with a simple weighing technique which optimizes the selection process in the implementation of this work. The weighing technique is necessary because of the multiple factors that the algorithm needs to consider before making a decision to initiate the handover process. We employ the rank order centroid (ROC) for the MADM weighing selection because it is less complex than the other techniques studied and also because we considered only four handover based metrics.

The development stage starts with the implementation of the Fuzzy logic inference system (FIS). We use the Fuzzy approach because it is an artificial learning (intelligent) process that mimics (approximates) human reasoning as closely as possible. It computes based on "degree of truth" rather than the conventional "true or false" (1 or 0) Boolean logic. The Fuzzy tool box in MATLAB is used to generate the rule base of the linguistic variables defined as Fuzzy sets. The input parameters are fed into the Fuzzifier and a single output is then generated by the defuzzyfier, this single output value is compared to a pre-set threshold and the handover process is triggered based on the outcome of the comparison, which is responsible for the human reasoning approximation earlier mentioned.

A series of requirements need to be met for our simulation to be credible. Firstly, the simulator must be able to handle wired and wireless networks, it must be able to implement multi-node devices, accommodate the accepted standards etc. The key IEEE 802.21 handover services include media independent service, media independent command service and media independent information service. IEEE 802.21 standard defines how operations such as network discovery and selection should work and how information regarding handover is shared to the network selection entity. The Wi-Fi, UMTS, WiMAX and LTE network topology is designed with OMNeT++ in the loose coupling mechanism, OMNeT++ simulation together with MiXiM framework is used for the implementation and simulation of our work because it accounts for the basic requirements mentioned above and it is user friendly . The parameters considered for the simulation of this work include the integration of the handover codes generated from the Fuzzy tool box in MATLAB, developing the codes for the HetNet using the inbuilt framework of the simulator and defining all other parameters and constraints experienced in real case scenarios such as obstacles, fading etc. These are further explained in detail in the subsequent chapters. Our choice of simulator also stems from the fact that OMNeT++ is a powerful simulation tool that adequately simulates communication networks, it is user friendly and accounts for most of the constraints encountered in practice.

Evaluation in Engineering mostly means a repetitive or iterative number of repetition while adjusting various input variables and holding certain variables constant. In our case, we write codes for the simulation of the two basic handover types as defined in this work (multi-criteria and single criterion) and then execute the simulation run for both handover types for a fixed time duration. The event logs are recorded for all the simulation trials to verify the output results and then our conclusions/solutions based on all the scalar and vector results obtained throughout the simulations. The system model design parameters are further explained in detail in the subsequent chapters. There, we provide expressions for signal level received by base stations, define distances apart for base stations, number of mobile nodes used for the simulation, number of access points, dimensions for playground, defining how we arrive at the back-off delay, defining the universe of discourse for cell coverage area, jitter, relative signal strength and bandwidth. Our choice of coding technique, fading techniques, assumptions and other necessary factors.

Our solution/conclusion is based on the evaluation of the simulation results. The results as displayed using charts, screenshots and other statistical data obtained interpret the handover probabilities, latency, call dropped rates, throughput etc. of our work.

4 Fuzzy Inference System

There are various techniques developed for the process of network selection and three main issues are of great consideration in this selection process. Firstly, the trouble of identifying and selecting the most appropriate parameters; secondly, the identification of an algorithm which can adequately exploit these identified parameters and thirdly, the application of a weighting technique to weigh each criterion.

Four main selection techniques have been identified and widely used are;

I. Utility Theory
II. Game Theory
III. Fuzzy logic and Neural Networks
IV. Multiple attribute decision making (MADM)

Radio signals can be said to be described in a fuzzy manner thus a handoff algorithm which is capable of making decisions when there is imprecise and incomplete information is appropriate. The Fuzzy Logic system is designed to imitate the human way of reasoning as much as possible in a given situation hence our choice to employ the Fuzzy logic approach in this work. It starts and builds on some supplied human language rules with no clear cut boundaries then converts them to mathematical equivalents. This concept has been defined as a generalization to classical sets that allows objects take partial membership in vague concepts. We can safely say that a Fuzzy set is one without a crisp boundary and is characterized by a membership function which defines the degree of membership of the elements contained in that set. Fuzzy Logic is a system of non-digital (continuous and fuzzy without crisp boundaries) set theory and rules. It is a process that draws conclusions from a set of facts using a collection of rules termed inference [36]. Thus, the Fuzzy inference system (FIS) is a computing frame work based on the concepts of fuzzy set theory, Fuzzy IF-THEN rules and Fuzzy reasoning. The expression below is a generalization to classical set where μ_A: U →[0,1] defines the membership function as mentioned above, of the Fuzzy set A.

$$A = \{(x, \mu_A(x))| \in X\} \qquad (4.1)$$

Similar to set theory operations of intersection and union, the Fuzzy logic operations conjunction and disjunction represent "*and*" and "*or*" respectively. Various articles have different choices for this operations, we will adopt the *minimum (min)* and *maximum (max)* to represent the operations.

Also, just like in set theory, the intersection of two fuzzy sets A and B can be expressed as another Fuzzy set C = A *AND* B with membership functions common to the Fuzzy sets A and B.

$$\mu_c(x) = \min\left(\mu_A(x), \mu_B(x)\right) = \mu_A(x) \wedge \mu_B(x) \qquad (4.2)$$

And in the same way, the union of two Fuzzy sets A and B is expressed as a third Fuzzy set

C = A *OR* B.

$$\mu_c(x) = \max\left(\mu_A(x), \mu_B(x)\right) = \mu_A(x) \vee \mu_B(x) \qquad (4.3)$$

The FIS is a system which computes and arrives at a conclusion based on the facts fed into it. Figure 9 below shows the block diagram composition of a FIS.

In this dissertation, we are focusing on ensuring quality of service in order to ensure quality of experience by the user. To guarantee quality of service, the network operators control certain factors such as available bandwidth, delay, jitter etc. It is also important to note that user satisfaction of services are often imprecise. During handover, we may expect packet loss, latency and other drawbacks thus we are compelled to consider the degree of seamlessness of the handover process. It is obvious that assigning an accurate, definite number to this degree of handover process seamlessness is not practical. This also is a reason why the Fuzzy based approach is adopted in this work, other important parameters include our choice of input parameters. The selected parameters are useful from a network service and technical point of view; the Four (4) input parameters fed into the system operating a Fuzzy based decision handover mechanism are:

- Available Bandwidth
- RSSI
- Jitter
- Cell coverage area

The mamdani FIS is used because it is known to be suited to human input, it is intuitive and is also widely accepted. Making decisions entails choosing the best possible alternative from multiple bases on which the alternatives are judged. It simply means selecting the best possible course of action or option. The MADM process is known to have three fundamental steps;

(i) structuring the problem (decision making)
(ii) acquiring the preference information

(iii) aggregation of the acquired preferences. This aggregation provides a unified value that spans across multiple attributes.

Structuring the problem requires identification of the attributes which characterizes the decision-making problem. A structure is then determined; hierarchical or flat structure. Next, the multiple attributes (alternatives) are also evaluated with respect to the problem structuring phase thus yielding attribute values that are subjective or factual judgments. These attribute values when properly encoded for the purpose of decision analysis are called preferential data. Lastly, the attribute values are aggregated using some weighing methods or a combination of weighing methods.

The Fuzzy based decision algorithm needs to be able to make a selection from a number of candidate networks, in our case LTE (A_{LTE}), UMTS (A_U), Wi-Fi (A_{Wf}) and WiMAX (A_{Wm}). Take for instance a mobile device connected to Wi-Fi cell 1 denoted as (A_{Wf1}) which needs to make a choice between five networks Wi-Fi (A_{Wf1}), UMTS (A_U), Wi-Fi (A_{Wf2}), WiMAX (A_{Wm}) and LTE(A_{LTE}) where Wi-Fi (A_{Wf2}) is a Wi-Fi cell outside the domain of Wi-Fi (A_{Wf1}) and the rest three candidate network options are cells with different access technologies as denoted respectively. We also denote the handover criteria jitter, cell coverage area, available bandwidth and RSSI mentioned earlier are denoted as $X_j, X_{cvrg}, X_{bw}, and\ X_{rssi}\ respectively$ for the sake of this example. It will be reasonable to presume that a handover from A_{Wf1} to A_{Wf2} may not necessarily be seamless due to the fact that they are not in the same domain, the decision scenario can be represented in a decision matrix form with the corresponding values of all network parameters. For the example stated, the decision matrix (D) is shown below, it is seen that networks A_{Wf1} and A_{Wf2} have high jitter and smaller cell coverage area compared to A_{LTE} A_U and A_{Wm} networks. We then have to introduce a method through which the system gets to select the best alternative network (A_{LTE} A_U and A_{Wm}) to handover the mobile device in a seamless manner for service continuity. The preference for the handover will be modelled as the weights assigned to the parameters and the rank order centroid (ROC) method is employed here. This method simply assigns weights to a number of parameters ranked in order of their importance, this ranks are inputs which are converted to weights for each of the parameters required for handover. The conversion for the ranks is based on the simple mathematical expression;

$$W_i = \left(\frac{1}{M}\right)\sum_{n=i}^{M}\frac{1}{n} \qquad (4.4)$$

Where M is defined as the number of network parameters considered for handover, W_i is the weight attributed to the i^{th} parameter.

$$D = \begin{array}{c|cccc|} & X_j & X_{cvrg} & X_{bw} & X_{rssi} \\ A_{Wf1} & 9.0 & 90 & 75 & -75 \\ A_U & 1.0 & 300 & 68 & -66 \\ A_{Wf2} & 7.9 & 100 & 70 & -74 \\ A_{Wm} & 3.5 & 200 & 80 & -70 \\ A_{LTE} & 0.2 & 100km & 30Mb/s & -66 \end{array}$$

Take for instance the four network parameters mentioned above, after assigning an order of importance, the item ranked first will be weighted as (1+1/2+1/3+1/4) /4 = 0.52, the second parameter in the ordered list of importance will weigh (1/2+1/3+1/4)/4 = 0.27, the third parameter will weigh (1/3+1/4)/4 = 0.15 and the last parameter will have its weight as (1/4)/4 = 0.06. We have decided to use the ROC weighing method because it is not as cumbersome as AHP and TOPSIS. Also since the number of parameters are few, ROC or SAW is probably the most suitable weight attribution method to employ.

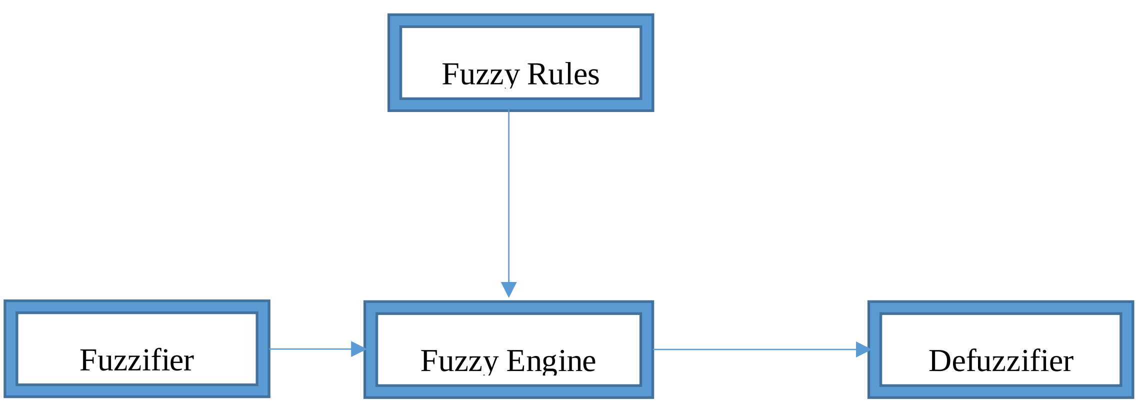

Figure 9.Mandani Fuzzy Inference System

The crisp input performance matrices are fed to the FIS via the fuzzifier which transforms these crisp inputs into degrees to match some defined linguistic values. The Fuzzy engine operates and generates outputs based on the Fuzzy IF-THEN rules and the output from the Fuzzy engine is fed into the defuzzifier which then transforms this inference result into a singular crisp output. In the case where a MN connected to the UMTS network detects a new network say Wi-Fi, the Mamdani FIS will calculate the handoff factor based on the input parameters been fed into the fuzzifier. The mamdani FIS has n-inputs but performs operations on these inputs to produce a single output. This single output (handover factor) from the defuzzifier is then used to determine if handover is required as it is compared to a pre-set threshold of 0.85.

i.e. if handoff factor from FIS > 0.85 initiate handoff.

The defuzzifier then aggregates the output Fuzzy decision sets to a single output (a precise quantity) during the final stage of the FIS. Each input parameter fed into the FIS will be attributed to one of the three defined Fuzzy sets:

{Strong (S), Medium (M) and Weak (W)}.

For example, the performance metrics RSSI set value will consist of the linguistic terms S, M and W. Each of these sets are then mapped to a corresponding Gaussian membership function. Traditionally, the RSSI is usually expressed in decibels with a given range 0 to -120dB with 0 been the strongest. Most academic materials state that RSSI levels less than -80db may not be useable depending on the noise level, this informs our selection of the RSSI universe of discourse in later section below. Wi-Fi signal strength is usually expressed as quality in percentage or an RSSI value in decibels, an appropriate correlation between the percentiles and relative signal strength can be described as;

db >= -50db = 100% quality or db <= -100 db = 0% quality

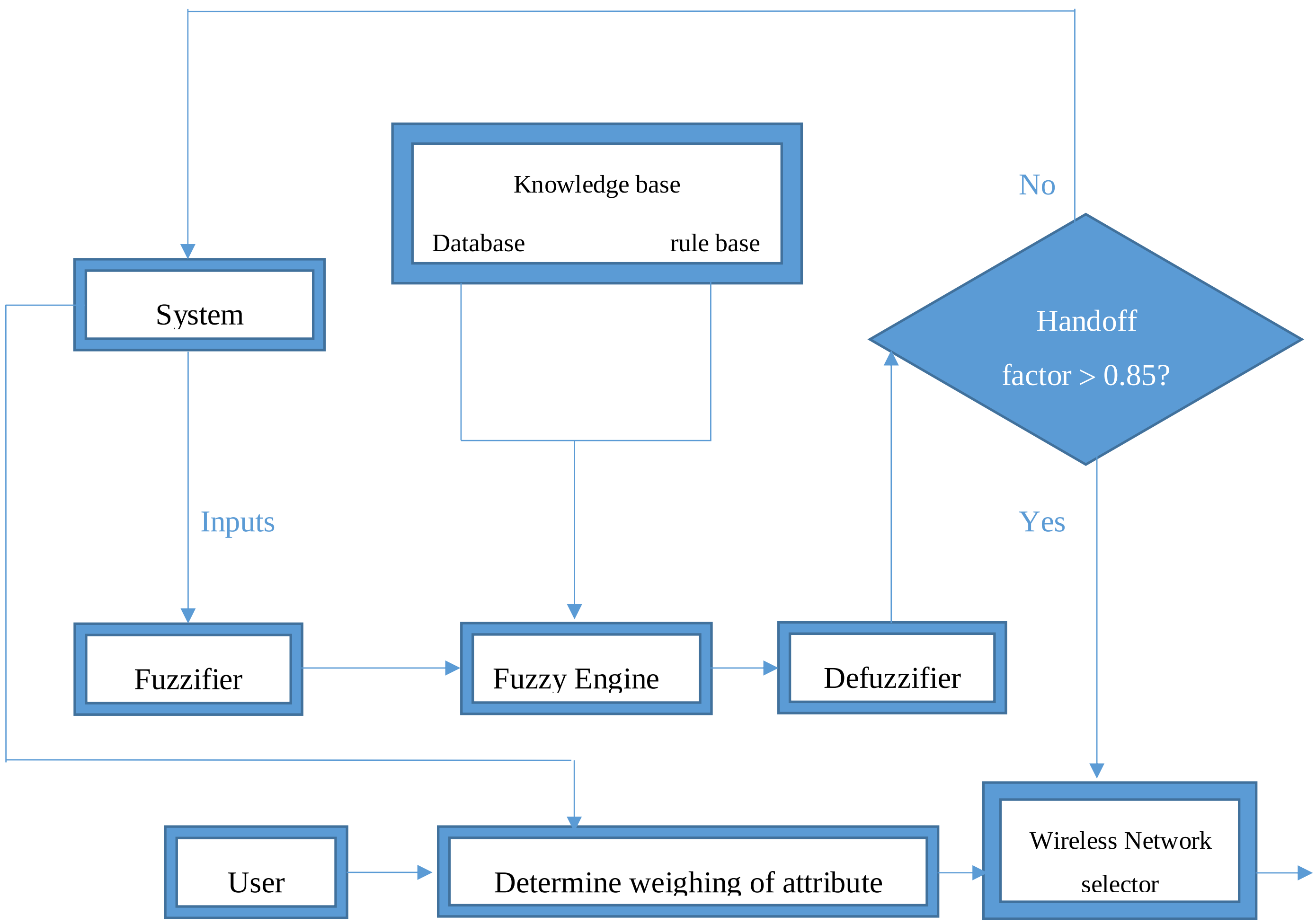

Figure 10.VHO Decision Flow Chart.

In this dissertation, we define the universe of discourse for parameter 1, the RSSI as -78dbm to -66dbm with the maximum RSS as -66dbm. Parameter 2, the available bandwidth has a universe of discourse defined from 0 to 80kbps, the network jitter has its universe of discourse defined between 0 to 10. Lastly, the cell coverage also referred to network coverage area has an area between 0 to 300M defined as its universe of discourse for both the UMTS and Wi-Fi networks. The following tables then define the membership functions and their mapping to corresponding ranges in the universe of discourse.

Table 2. RSSI (dBm)

	Range/Degree of Membership	
Linguistic Variable	Low	High
Strong {S}	-72 to	-66
Medium {M}	-78 to	-66
Weak {W}	-78 to	-72

Table 3. Available Bandwidth. Universe of discourse 0-56Mbps

	Range/Degree of Membership	
Linguistic Variable	Low	High
Strong {S}	40 to	80
Medium {M}	0 to	56
Weak {W}	0 to	22

Table 4. Cell (network) coverage. Universe of discourse 0-300m

	Range/Degree of Membership	
Linguistic Variable	Low	High
Strong {S}	0 to	100
Medium {M}	0 to	200
Weak {W}	200 to	300

Table 5. Jitter. Universe of discourse 0-10

	Range/Degree of Membership	
Linguistic Variable	Low	High
Strong {S}	7.5 to	10
Medium {M}	0 to	10
Weak {W}	0 to	7.5

We will then define five handoff factor ranges for the one output handoff factor as shown in the table below.

Table 6. Handover Factor

	Handoff Factor	
Linguistic Variable	Low	High
Higher	0.75 to	1
High	0.50 to	1
Medium	0.25 to	0.75
Low	0.00 to	0.50
Lower	0.00 to	0.25

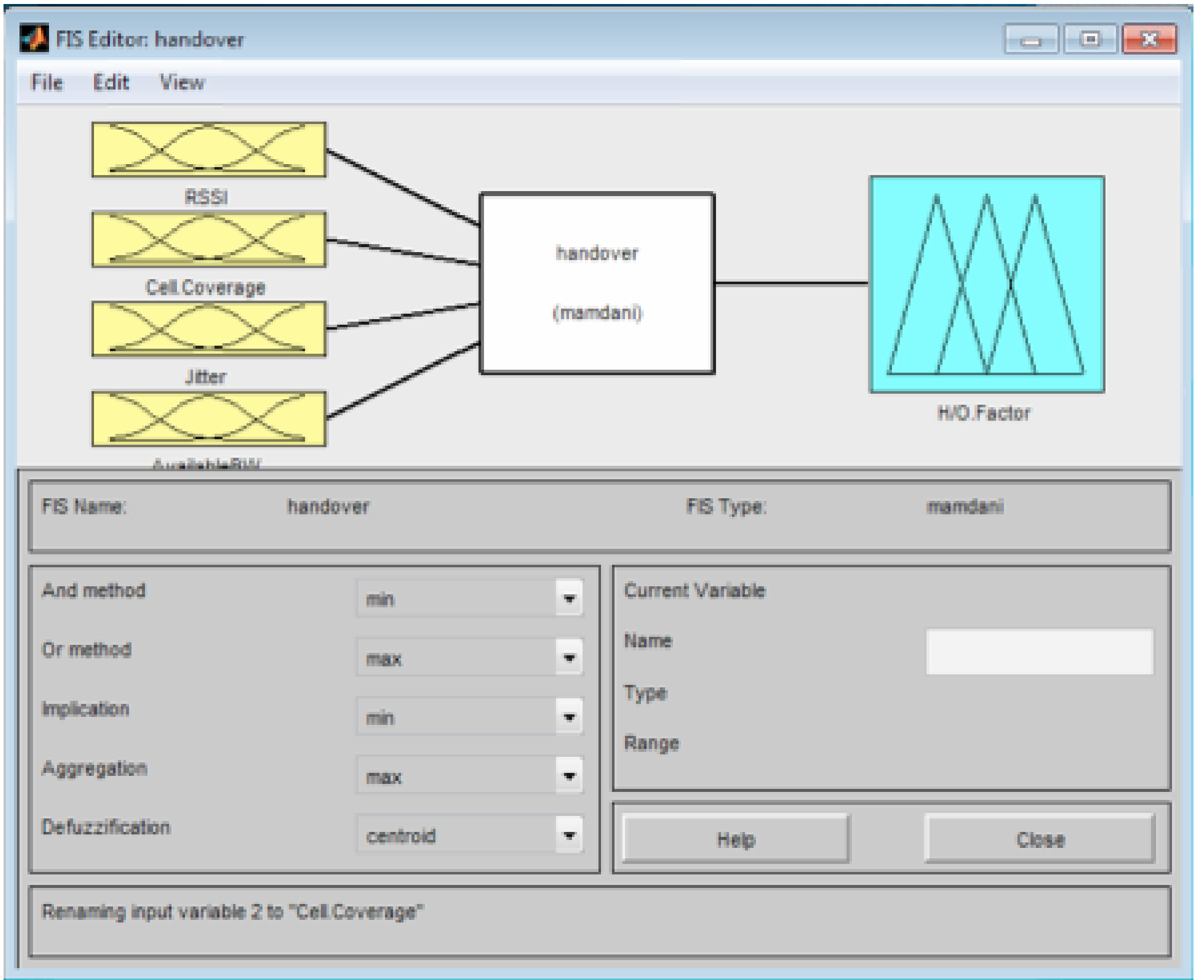

Figure 11.. Membership Functions

The maximum number of fuzzy rules generated is $3^4 = 81$ rules because we have four input parameters fed to the FIS and three Fuzzy membership sets for each variable. A few of the rules generated include:

- If (RSSI is weak) and (Ntw.coverage is weak) and (Jitter is weak) and (AvailableBW is weak) then H/O.Factor is lower) (1)
- If (RSSI is weak) and (Ntw.coverage is medium) and (jitter is medium) and (AvailableBW is weak) then H/O.Factor is low) (1)
- If (RSSI is strong) and (Ntw.coverage is strong) and (jitter) is medium and (AvailableBW is strong) then H/O.Factor is higher) (1). (All the rules are assigned the same weight 1).

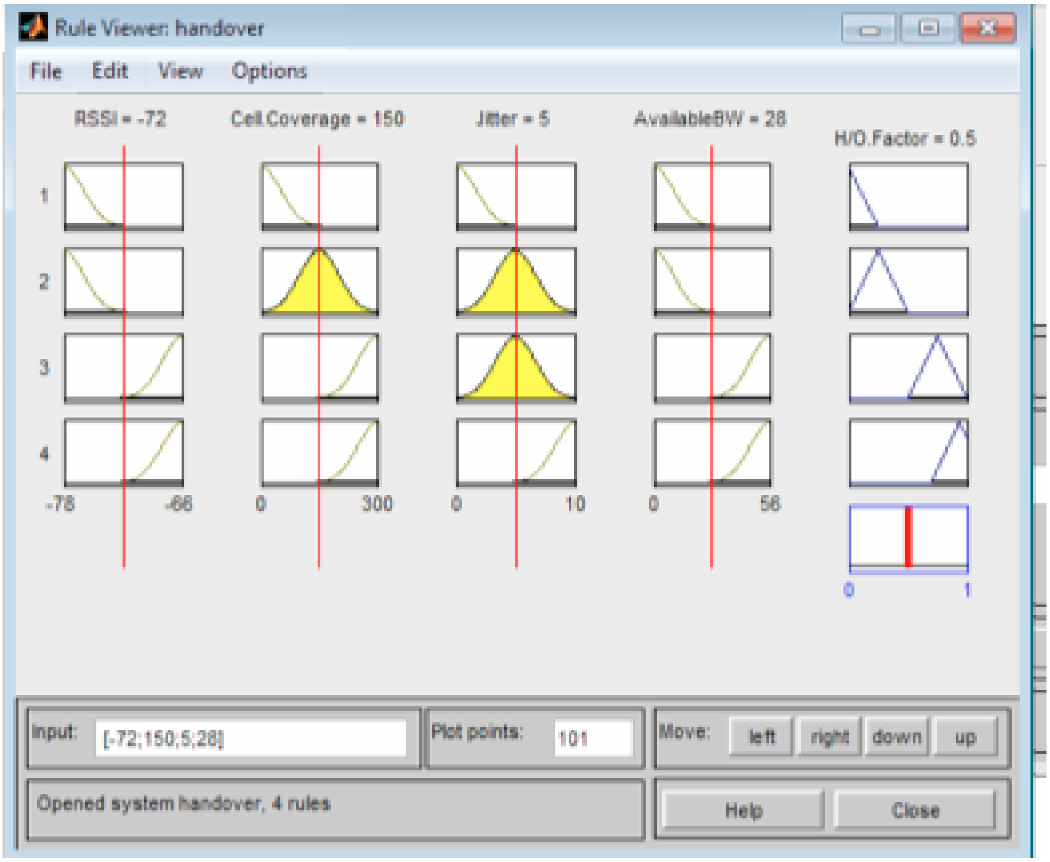

Figure 12.FIS display of the first four rules

Now, considering a mobile node currently serviced by the Wi-Fi access network. As it moves to a region where other access networks are available, the multimodal device starts receiving pointers i.e. the entire input variables for the network interface (available bandwidth, RSS, coverage area and network jitter). As these crisp input variables are fed into the FIS, its output is compared to the network performance of the current serving access network and then a decision on whether handoff is required is made. Figure 13 shows the surface mode of the relation between the inputs and the output of the FIS, a graphical mapping between any two inputs and an output.

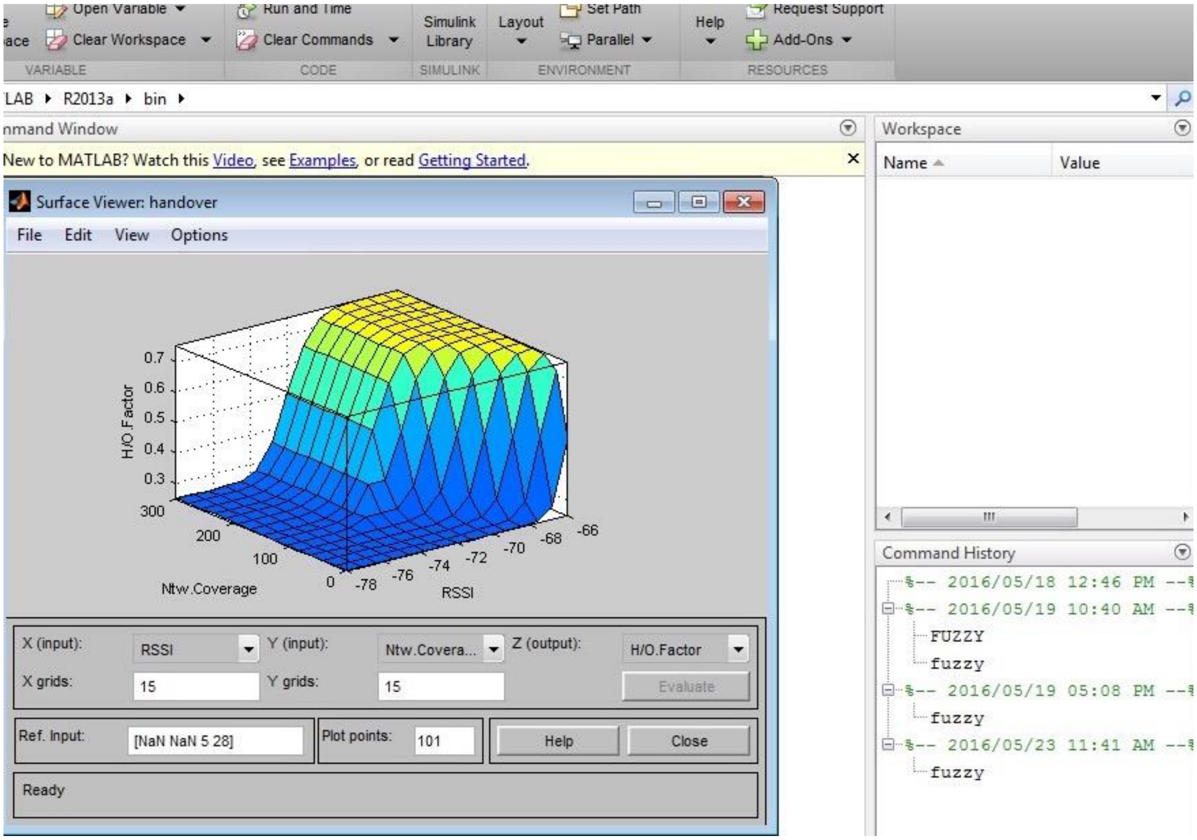

Figure 13.Correlation between inputs and output handover factor

Here we selected the cell coverage and RSSI inputs to create a 3D plot with the handover factor just to further help understand the fuzzy logic system designed. It shows that the handover factor increases (yellow) or decreases (blue) as input factors increase or decrease. The surface view is like an elevation or temperature map that helps show visually where outputs are low and where they are high. For the system to be able to perform an action, the outputs need to be converted into a scalar quantity, a process termed defuzzification. The Fuzzy system aggregates the Fuzzy output with the union set operator; the max of the membership function and is expressed in the relationship;

$$\mu_i = \cup_i \mu_i(x). \qquad (4.5)$$

Various defuzzificztion methods exist, literature has it that the most common and accurate technique is the centre of area (centroid) defuzzification, a technique developed by sugeno in 1985 as stated by T. J. Ross.

$$x^{\star} = \frac{\int \mu_i(x) x d_x}{\int \mu_i(x) d_z} \qquad (4.6)$$

$x^{\star}$ from the above equation is the *defuzzified output* and the aggregated membership function is the desired threshold $\mu_i(x)$. T. J. Ross further stated that the only setback with this technique is the difficulty associated with a case of complex membership function. The overall Fuzzy system designed for this work is represented in a functional block diagram having three main sections; the collection section, processing section and the assignment section shown below. The collection section basically listens and collects data for the attributes in order to assess the impacts of the network parameters on the network QOS.

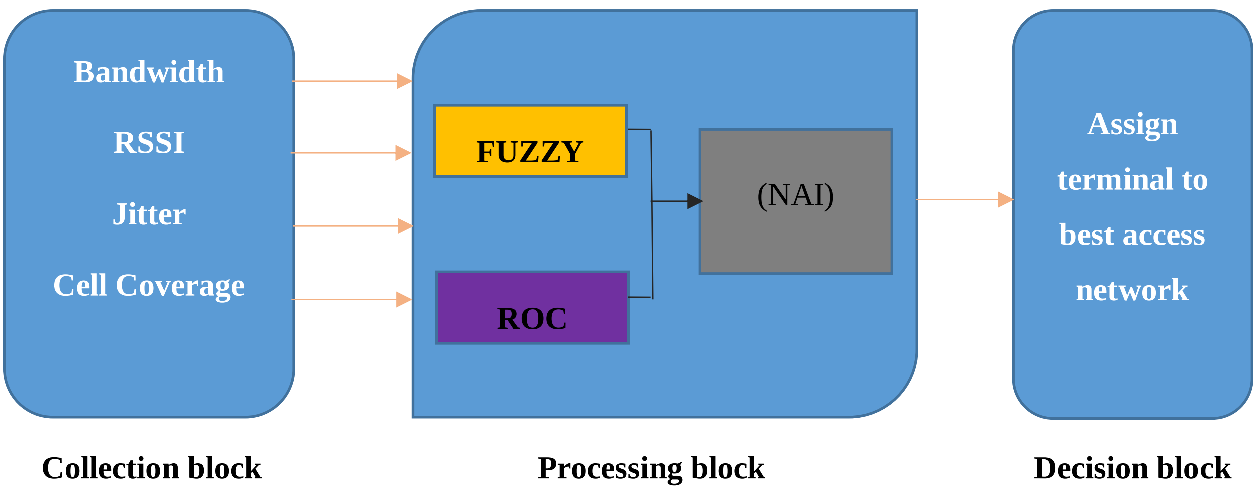

Figure 14.ROC, Fuzzy Architecture.

The processing block as shown in the figure above comprises of the Fuzzy inference system, the rank order centroid (ROC) and the network average index (NAI). The data stored from the collection block is processed by the fuzzy inference system while the ROC also receives this data for classification of the most adequate network in the environment where the mobile device is based on the weights of the parameters. This weigh attribute is in respect to the type of traffic or application running, the known traffic types are the real-time traffic (audio, video) and non-real time traffic (MMS, SMS). For the real-time traffic, the fuzzy system works with the widely accepted and know threshold for transmission of voice traffic (VoIP) which emphasizes that the delay and jitter should be considerably less 300ms and 150ms respectively while packet loss must be less than 1% and 3% for video and voice respectively to avoid sound ineligibility to the human ear [34]. This threshold setting also serves as the basis for the classification of the linguist variables (strong, medium and weak) defined earlier in this work and the outcome generated by the Mamdani triangular membership function. The score of each network is informed by the output of the fuzzy system (deffuzification) and the output from the ROC from each criterion bearing in mind the weights are based on the importance of the parameter with respect to the type of traffic. Take for instance, the mobile user has voice and file download applications running, the network preference is modelled as weights for the handover criteria W_v and W_f. The model is in such a way that the summation on each criterion equals the numerical value one. W_v = [weak, medium, strong, strong], W_f = [medium, medium, strong, strong].

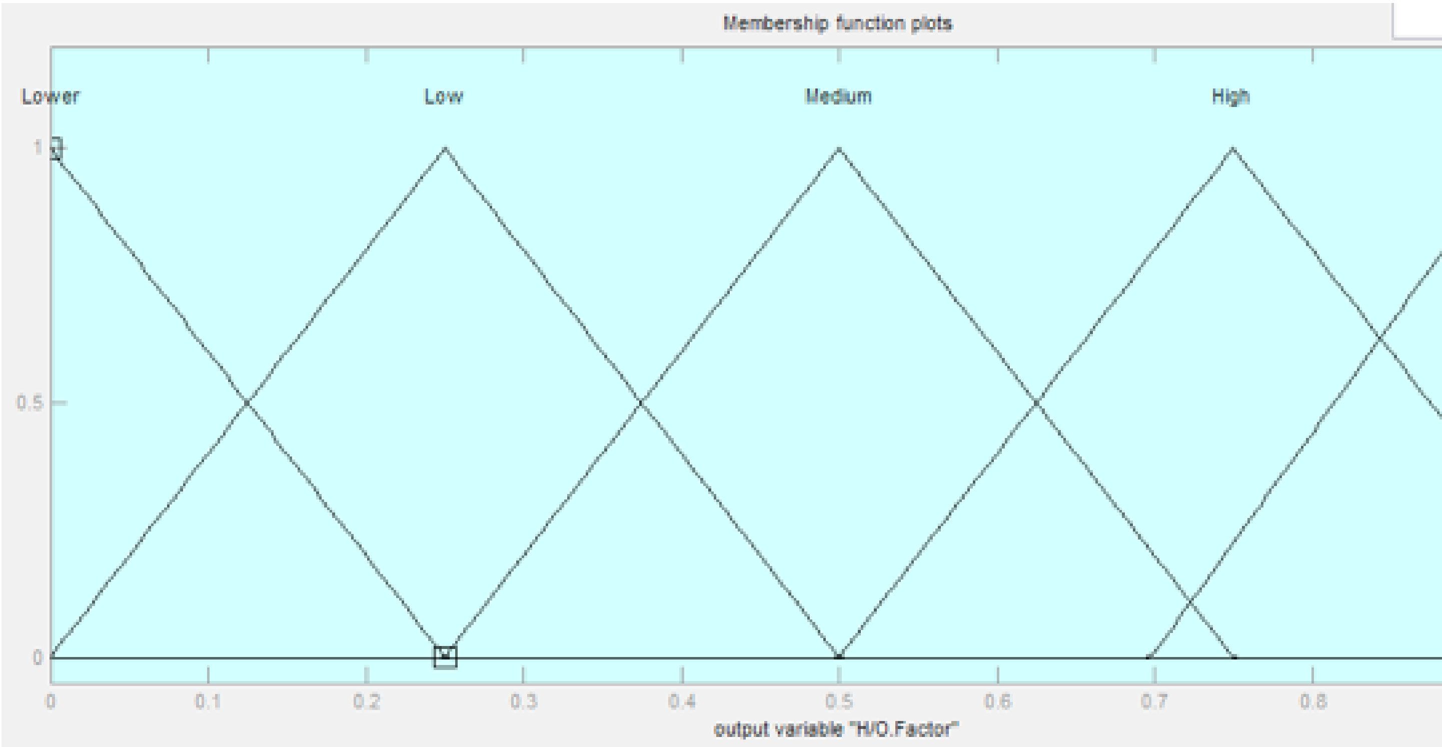

Figure 15.Linguistic term to Fuzzy number conversion scale

Lastly, the decision of the best available network for continuity of service is arrived at by the network average index output. The NAI results from the arithmetic average of the results generated from the ROC and fuzzy inference system of the processing block. Thus, in summary, the procedure adopted in this work is a Fuzzy MADM method with two basic steps. First is the conversion of the Fuzzy data into a single output (real number) and the second step uses a weighting method to determine the suitable candidate network with respect to the traffic type. The introduction of an intelligent network selection method (weighting method) prevents the mobile terminal form performing excessive and unnecessary handovers. This is achieved in the simulator by assigning back off time slots as unnecessary handoffs causes ping pong effects which leads to increasing power consumption and a decreasing network throughput.

5 I-RAT Framework and Requirements

A very important issue that requires consideration in the quest to achieve seamless handover in HetNets is the interworking architecture. The type of coupling methods employed for the connection of the components that constitute the different access networks contributes to the efficiency of the inter-RAT handover management. As earlier mentioned, the different type architectures are defined based on the point of attachments as explained later in the chapter. In recent years, standardization bodies have proposed and released their respective internetworking solutions defined for convergence of HetNets; the 3GPP and IEEE organizations. More details regarding procedures for selection of suitable cells by a MS for connecting to 3GPP cellular networks can be gotten from the series of works by J. P. Romeo et al 3GPP TS 25.331; 3GPP TS 43.129; 3GPP TS44.060; 3GPP TR 25.931(2005). IEEE 802.21has proven to be a promising solution to vertical handoff, it defines a generic link layer to mask the heterogeneities of various RATs [13]. Basically, when a mobile device is powered on, it must first select a PLMN and a RAT either manually or automatically. Registration in the selected cell is then carried out, i.e. the MS registers its presence and provided this mobile device remains in the idle mode this process continues. Events such as high path loss, downlink signaling failure etc. are reasons for this continuous reselection procedure of the mobile node as it tries to camp on the most suitable cell of the chosen PLMN. When the new cell selected falls in a different registration area, there is then a prompt for a Location Registration (LR). Consider a network operator that provides reliable access based on a number of different wireless technologies (LTE and WiMAX). Operations such as authentication, billing and QOS management must be sure to work seamlessly as mobile equipment move through the network. The classic organisation of wireless networks is adopted here where each different technology is separated in an autonomous network, this is aimed at reducing the complexities involved. Different requirements exist for I-RAT handover on the two sides of the network [22] i.e. from the UE side and the network side and the main requirements are listed below. From the UE side, the basic requirements include:

- device supports the two modes of operation (3G and 4G).
- UE can carry out measurements on different frequencies (I-RAT measurements), this factor is critical because this measurement process must be done in such a way that there is no schedule for transmission when there is a break in measurement.

From the network side, requirements include:

- Agreements and MOU’s on mobility between LTE and WiMAX where user is notified in the case of service degradation when transiting from one technology to another.
- Billing and accounting must be handled appropriately.
- The subscriber identification must be compatible. i.e. can be used in an all LTE environment and in that of WiMAX.
- Security is also a key aspect from the network point of view (Sharing of database or keeping it separate)

3GPP defined different internetwork scenarios based on the QoS they offer the mobile node, each of these internetworking scenarios having different requirements and architecture [13]. Four scenarios have been defined from the architectural view point as listed below.

I. Open Coupling: Billing is common between the internetworks using different authentication mechanisms, however they all own separate transport and access networks.

II. Tight Coupling: In this case, functions which are available in the RAN can be executed by the WLAN as it connects directly with the 3G core network. Data from WLAN network passes via the 3G/UMTS core network then to internet or packet data network PND. In this context, each network will modify their protocol interfaces and services for supporting interworking requirement. In a tight coupling, the interconnection with WLAN can be made at a core level (GGSN, SGSN) or Access level (RNC) [13].

III. Very Tight Coupling: In this approach, the difference when compared to the tight coupling is that the WLAN is connected as part of the UTRAN and the new interface defined interconnecting WLAN in the RNC of the UTRAN.

IV. Loose Coupling: In this arrangement, the networks independently interconnect providing independent services and utilizing one common subscription. The internetworking point in this architecture is after the interface point of GGSN (Gateway GPRS Node) with the IP network and the network interconnection uses MIP mechanism for mobility between WLAN and UMTS [12]. Figure 16 below used by T. A. Yahiya, H. Chaouchi, in “integration of LTE and Mobile WiMAX Networks” [22] is a pictorial view of a loose coupling scenario, the connection type adopted in this work.

The two coupling architecture types that have been categorised as less complex and flexible are the loose coupling and tight coupling architecture [37]. However, various studies have it that they often suffer from longer handover latency within the range of hundreds of milliseconds to some seconds. The integrated coupling architecture has shown better handover performance but with a trade-off of the complexities introduced at the network protocol stacks [10]. The bulk of the complexity encountered in this type of work mostly occurs from the network side of the connectivity; trigger points for the handover, measurement criteria configuration, signalling of the parameters to UE etc. all must be correctly co-ordinated by the eNodeB. There are two common ways to the internetworking of LTE and legacy 3G networks as stated by Olsson et al [23]. He explained that the PDN-GW is used as the anchor point in the I-RAT network and no interfaces between either of HSS and SGSN or the S-GW and SGSN. The mobility details such as mobile IP and load balancing data traffic will not be discussed as it is beyond the scope of this work. The same tunnelling protocol is used in both networks and this internetwork of LTE and WiMAX is based on this protocol. This is where loose coupling is achieved as all data passes through a single point of attachment. As earlier stated, network integration holds possibilities for hybrid solutions for device based integration to network-level Integration. In Enabling multimedia aware vertical handover Management in Internet of Things based heterogeneous wireless networks [37], the author addresses the issues presented in the current handover management schemes. Issues enumerated include wrong network selection, handover delay, inappropriate handover triggering etc. proposed a generic vertical handover management scheme in a loosely coupled network architecture. In this proposed management scheme, the mobile node dynamically checks the data rate required by whatever application running on the device. A situation where this data rate then drops below the predefined set threshold then the mobile node initiates the handover process. The second aspect of the management scheme requires consideration of various parameters before network selection is done. Lastly there is a comparison in context of network throughput, energy consumption, average MN's stay time in the network, handover time and handover delay time of this selection method employed with Simple Additive Weighting, (SAW), Weighted Product Method (WPM), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Fuzzy TOPSIS methods. The experimental results for the loosely coupled internetwork is seen to outperforms the mentioned schemes when used for the same purpose.

A. B. Zineb et al, in An Enhanced Vertical Handover Based on Fuzzy Inference MADM Approach for Heterogeneous Networks [38] also experiments setting up the same loosely coupled internetwork architecture to analyse seamless handover in HetNets. Performance of roaming is hinged on the number of implemented handover criteria. They however introduced a compromise ranking method called VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR). The efficiency of the novel proposal is evaluated through simulation and the result showed the mechanism performed well from the battery level life, maintenance of QoS and reduced handover delay time.

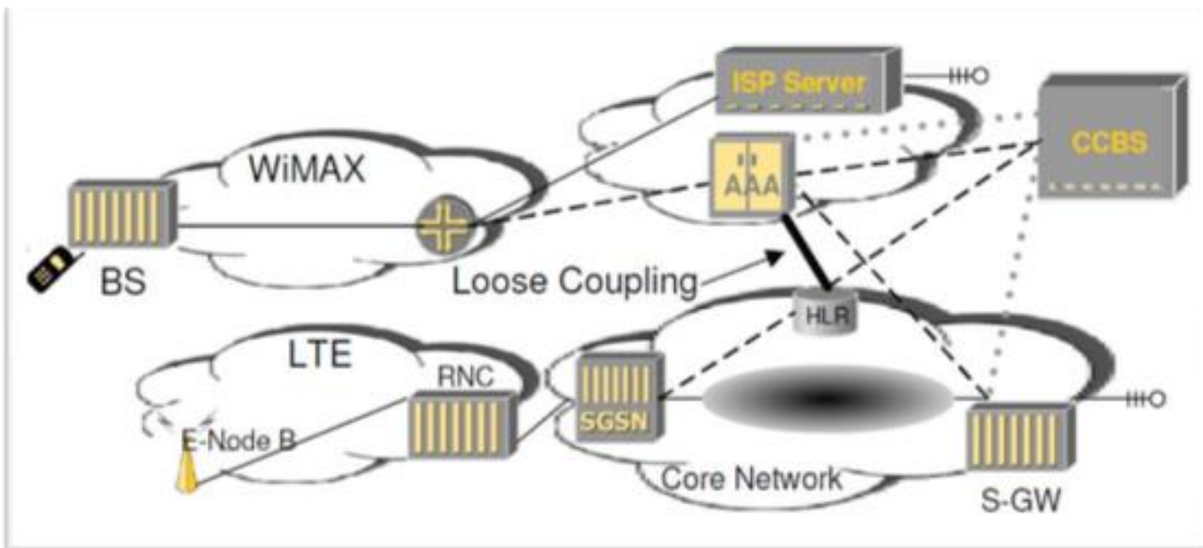

Figure 16.Loose Coupling Network Integration (LTE and WiMAX) [22]

Van. D. D et al [39] adopts a similar heterogeneous network architecture (Wi-Fi, UMTS and LTE) in his work; vertical handover algorithm for WBANs in ubiquitous healthcare with quality of service guarantees. Here, the loose couple inter-network connection is the bedrock for the wireless body area network (WBAN). This internetwork was designed for the healthcare sector, comprising of developed coordinator devices which are installed on patients. The devices together with the network architecture and protocols enables delivery of critical physiological information like heartbeat rate, blood pressure, body temperature ECG, EEG, EMG etc. gathered, monitored and disseminated remotely to the healthcare staff department. They further employed an effective MADM handover algorithm to guarantee seamless handover in the heterogeneous network. The simulation results showed impressive performance of the algorithm in terms of the energy efficiency, number of handovers, enhanced QoS and minimal packet loss.

The following chapter introduces the OMNeT++ simulation framework and its components. The loose coupling architecture explained above is implemented using the simulator. The other parameters and procedures explained in the preceding chapters are also implemented, the simulation trials are ran and then the various results recorded and interpreted.

We adopt the loose coupling scheme because we intend to work with less complexities, also for the fact that the modifications to technologies and the network architecture are few. However, studies have it that a drawback of difficulty in the performance of layer 3 handover performance due to the high level of integration. Another reason the choice of loose coupling is that tightly coupled architectures propose integration at lower level of network architecture as such the complexity during implementation increases, and more modifications must be operated to technologies and core network architecture [13].

6 OMNeT++ 4.4.1 Simulator

In this section, we attempt to give a concise description of the simulation process. We start by installation of JDK 1.6 and OMNeT++ 4.4.1 on windows 7 operating system. The OMNeT++ 4.4.1 is an integrated development environment based on the Eclipse platform, it has extended functionalities for creating/configuring network models (NEDs & files) with new editors, views, wizards performing batch executions, analyzing and simulating results. OMNeT++ is C++ based, supports GUI/parallel execution (MPI based), runs on windows/Linux and is free for academic use. Since OMNeT++ is designed to provide a component-based architecture, the models or modules of OMNeT++ are assembled from reusable components. Modules are reusable and can be combined in various ways which is one of the main features of OMNeT++. [40]. Other features of OMNeT++ simulator include; the simulation kernel, the compiler, the code required for the NED topology description language, graphical network editor for NED files (GNED), GUI for simulation execution (Tkenv), command line user interface (Cmdenv), graphical output scalar visualization tool, model documentation tool, utilities and documentation.

6.1 Network Entities and functions

I. Node module- All entities that establish a communication with another. In MiXiM, all the nodes are specified as terminals or access points with capabilities of different functionalities (Bluetooth, ultrasound). The node module comprises the standard layers according to IP model (Network layer and application layer physical layer, MAC layer,).

II. Mobility module- This handles the movements carried out by the node or objects.

III. Battery module- This module is responsible for all energy related issues. E.g., simulating the battery drainage of a sensor node due to processing is possible.

IV. Utility module- This basically provides a general interface meant for the collection of statistical data, it also maintains every other parameter that will need to be accessed by more than one module within a node.

V. World utility module- This is where the environment model is contained. It allows for the collection of global parameters such as dimensions of network, graphical representation (2D/3D) and objects to model the environment.

VI. Connection Manager- Is the central module which controls all connection related stuff such as connection between nodes, dynamic handling of gate creation etc. Therefore, it periodically communicates with the mobility module and Channel Access throughout the simulation process. The four parameters pMax, sat, alpha, and carrier Frequency are used to calculate the interference distance between nodes. The values used here in Connection Manager are used to calculate the upper bound, i.e. they can be redefined in the analogue models, but never such that the maximal interference distance is exceeded.

One of the main challenges in VHO simulations is the problem of building custom models, this is adequately taken care of by employing OMNeT++. It has integrated IDE and its compilation/execution is a lot different form the version 3.x, it is also important to turn off the anti-virus installations because with the mixed module nature, the anti-virus gets to delete files and OMNeT++ will run with errors. The two major installation commands are the ". /configure" command which sets up all the parts of the directory in the installation folder and the "make" command compiles and prepare OMNeT++. The framework structure eliminates the need for any raw coding; framework for power, framework for application, framework for graphs, multipath, optimization etc. are all supported (framework is a set of codes and libraries). Hence you simply select or identify the part/point in the framework to use and adjust the parameters to your design and preference. The functions of the important aspects of OMNeT++ enumerated above are briefly as described below.

- Model structure- OMNeT++ model is made up of different modules which are in constant communication with message passing through. The active modules otherwise known as simple modules are written in C++ using the simulation class library [40]. The messages that are sent can be sent either from the direct connection to their destination or via connections that span between modules. The simple and compound modules are instances of module types; the user defines the module types while describing the model and these instances then serve as components for more complex module types. The feasibility of module reuse is proven by frameworks like INET framework, mobility framework etc. Messages are sent via gates, they serve as the inputs and outputs interfaces for the modules, they are linked to one another via *connection*.
- The Design of the NED language- NED descriptions simply hold simple module declarations, network definitions and compound module definitions.

- Graphical Editor
- Simple Module Programming Model
- Parallel simulation support

6.2 Simulator Requirements (MiXiM, SimuLTE) and Procedure

MiXiM is a mixed simulator for wireless and mobile networks simulations in OMNeT++ engine. Although OMNeT++ is a standard, powerful simulation framework tool for the study of protocols of wireless and wired networks it still lacks the direct support and concise modelling chain for wireless communication [41]. MiXiM is designed to provide both, it is a combination of different simulator frameworks that provides detailed models and protocols as well as supporting infrastructure [40, 42]. The MiXiM approach is used here because it offers an easy to use interface, provides a plethora of possibilities to invent or improve new protocols and also has default settings to parameters such as minimum path loss for 3GPP suggested propagation models [41]. It also facilitates the development and implementation of specific models and protocols for wireless communication without having to worry about the underlying architecture more than necessary [42]. Some of MiXiMs outstanding features include the highlighted;

- Connectivity and mobility- The simulator tracks changes on nodes due to the mobility of another node. This changes are graphically represented by the simulator.
- Reception and collision- The various parameters which influence the reception of a message in a wireless network are well captured. The reception handling takes care of modelling changes on the transmitted signal via the channel to the receiver taking transmission of other senders into account.
- Experiment support- Experiment support allows scholars compare results with an ideal case. Different evaluation methods including various templates for implementation are supported.
- Environment models- During simulations, the relevant parameters (e.g. obstacles) in the real-world scenario are easily reflected.
- Protocol Library- It allows comparison of research ideas with already implemented protocols.

As earlier stated, MiXiM combines approaches from different existing simulation frameworks to form one, this is the reason why it is able to provide these solutions. The mobility support, connection management, and general structure is taken from the Mobility Framework (MF) [41]; the radio propagation models are taken from the CHannel SIMulator (ChSim) [32] and the protocol library is taken from the MAC simulator [43]. MiXiM can be categorized logically in to two parts; the protocol library and the base frame-work [44], the general functions for any wireless network is provided by the base frame-work while the protocol library on the other hand supports the base frame-work with a rich set of protocols including mobility models. The rich protocol library made the implementation of the Fuzzy rule set on OMNeT++ simulator easier in this project. Modelling and simulation of wireless and mobile networks from MiXiM framework is simply imported into the existing projects directory on the OMNeT++ simulator after its compilation. The SimuLTE on the other hand is an innovative tool that enables performance-evaluation of complex systems such as LTE and LTE-Advance networks. This simulation tool is written in c++ with fully customizable pluggable interfaces that allow implementation of new algorithms and development of new modules. SimuLTE is open source and can be used on any system compatible with OMNeT++. The main features of SmuLTE include;

E-NodeB: Micro, macro, pico eNodeBs, inter-eNB coordination through x2 interfaces, supports scheduling algorithms, CoMP, and handover processes.

MAC: CQI reception, buffering, resource allocation, selecting transport format, PDU concatenation coding designs etc.

RLC: AM and UM segmentation reassembly and also AM retransmission

APPS: VOIP, video streaming, real time gaming FTP are all applications supported by the SimuLTE.

PHY: transmits diversity, computation of channel feedback etc. Open source simulations are freely available but to the best of my knowledge none is known to fully simulate the LTE system thus strategies have been designed for its optimization. Literature works have shown that to adequately cater for this, the open source frameworks that are usually used to simulate LTE networks are the LTE-Sim, and the SimuLTE. the latter is employed in this work due to its compatibility with

OMNeT++. Below is the implementation of the Fuzzy code for the OMNeT++ simulator framework.

```
#ifndef CONNECTIONMANAGER_H_

#define CONNECTIONMANAGER_H_


#include "MiXiMDefs.h"

#include "BaseConnectionManager.h"


/**

 * @brief BaseConnectionManager implementation which only defines a

 * specific max interference distance.

 *

 * Calculates the maximum interference distance based on the transmitter

 * power, wavelength, pathloss coefficient and a threshold for the

 * minimal receive Power.

 *

 * @ingroup connectionManager

 */

class MIXIM_API ConnectionManager: public BaseConnectionManager {

protected:


    typedef enum RSSI {

        rStrong, rMedium, rWeak


    } rssival;
```

```
typedef enum bandw {
    bStrong, bMedium, bWeak

} bwval;

typedef enum nwcov {
    nStrong, nMedium, nWeak

} nwval;

typedef enum jit {
    jStrong, jMedium, jWeak

} jitval;

typedef enum handoff {
    Higher, High, Medium,Low ,Lower

} hofval;

/**
 * @brief Calculate interference distance
 *
 * Calculation of the interference distance based on the transmitter
 * power, wavelength, pathloss coefficient and a threshold for the
 * minimal receive Power
 *
```

```
            * You may want to overwrite this function in order to do your own
            * interference calculation
            */
           virtual double calcInterfDist();

          // hofval FuzzificationRSSI(rssival vel,bandw tden,nwcov ccon,jit
ji,hofval hval);
           rssival FuzzificationRSSI(rssival vel);
           bwval Fuzzificationbandwidth(bandw tden);

           nwval FuzzificationNetworkcover(nwcov ccon);
           jitval Fuzzificationjitter(jit ji);

           hofval Fuzzificationhandoff(hofval hval);

       };

#endif /*CONNECTIONMANAGER_H_*/
```

The 3GPP suggests a couple of propagation models used for path loss prediction at 2GHz band and among them is a model dedicated to eNodeB-relay links [41]. The path loss used in the simulation are default settings and they conform to the propagation models as given by 3GPP. The loose coupling type architecture was adopted in this dissertation (i.e. the networks are independently deployed and the Wi-Fi, WiMAX data does not pass through the core network) because the internetworking point occurs only after the 3GPP core network as this reduces the network complexity which in turn reduces cost. The table below shows the parameters for the performance evaluation of the OMNeT++ simulation model. For fair comparison and to reduce simulation complexity, we assign the same values for some of the common parameter in the configuration setup for the different access network types.

Table 7 Simulation Environment Parameters

System Parameters	
Coverage Area (UMTS)	200m, Ellipse
Coverage Area (Wi-Fi)	100m, Ellipse
Coverage Area (WiMAX)	150m, Ellipse
Coverage Area (LTE)	600m Ellipse
Simulation Time Limit	200s
Transmission Power (UMTS, Wi-Fi LTE)	30mw, 20mw, 46dBm
Minimum Path Loss Wi-Fi	2
Path Trajectory	Linear
Beacon interval	1s
Number of Nodes (Mobile Users)	10
Number of Wi-Fi Access Points	3
Minimum Path Loss Wi-Fi	Default settings
Minimum Path Loss LTE	Default settings
Minimum path loss WiMAX	Default settings
Playground	1000m
Wireless Protocol	802.11
MAC Type	MAC1069_4
NIC Type	NIC80211P
Mobile device velocity	2.8m/s
Traffic Type	VoIP
Carrier Frequency	5.890e9 Hz
Sensitivity	-94dBm
Min. SINR threshold	-6.5dB

Video, voice and data traffic types are the commonly transmitted traffic types in any communication network system. The performance evaluation of these traffic types does not only depend on the traffic itself but also on the technologies together with the overall structure of the network (wireless or wired) and other factors such as the distance/speed of the user equipment from the base station. OMNeT++ provides different codec types, we select the G.711codec scheme which supports pulse code modulation (PCM) and has a compression/decompression delay of 0.02 seconds each. The type of service used for the VoIP call is the interactive voice, we set the start time with an offset of "60"+ start time (seconds) so that the establishment of the VoIP call application is repeated until the simulation runtime is completed. In OMNeT++. the packet delay variation (PDV) is arrived at by computing the variance of the packet delay and the end-to-end of the total voice packet delay calculated as

$$\mathrm{D_{e2e}} = \mathrm{D_n} + \mathrm{D_d} + \mathrm{D_{de}} + \mathrm{D_e} + \mathrm{D_c} \qquad (6.2.1)$$

where $\mathrm{D_n}$, $\mathrm{D_d}$, $\mathrm{D_{de}}$, and $\mathrm{D_c}$ represent network, decoding, decompression and encoding delays respectively. PDV is key in the analysis of any networks performance because it affects the user's perceptual quality. With a relatively high PDV, congestion of packets occurs form resulting network overhead which can also lead to packet loss. The subsequent diagrams below give the analysis of the output results of the simulation runs. For those communication applications involving digital continuous media (interactive and non-interactive applications) to achieve acceptable quality for animated images and sound (a bound on the delay and jitter is required). As earlier stated, a jitter of less than 150ms for one way or overall of less than 300ms is recommended by the International Telecommunications Union, while packet loss must not exceed 3% [45, 46] otherwise the sound is illegible to the human ear. In the case where the latency jitter is more than the above-mentioned time limits, then there is a notification so that techniques to prevent VoIP jitter are engaged [47]. Techniques such as prioritizing VoIP traffic over the network, reserving more bandwidth for phone conversations, optimizing packet size and jitter buffering etc.

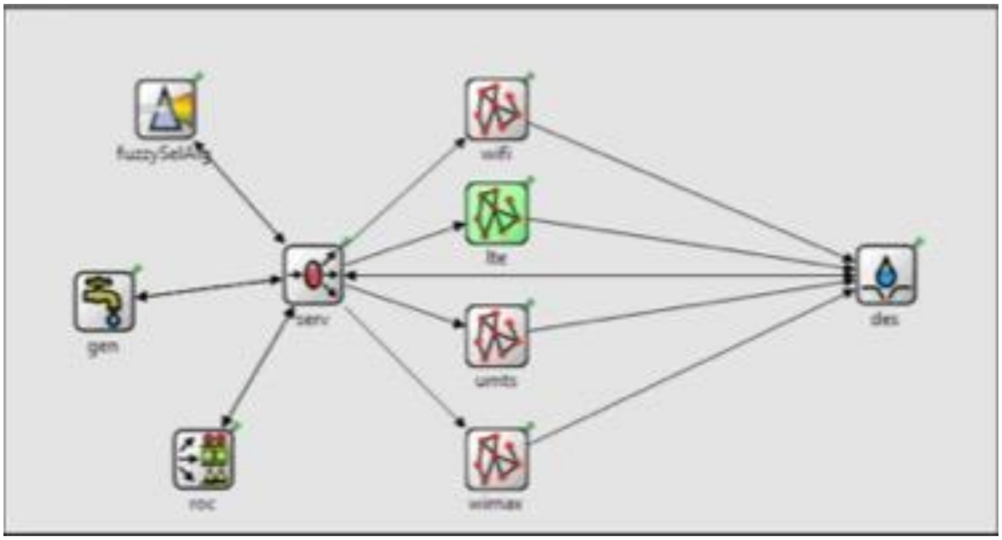

Figure 17.OMNeT++ VoIP Traffic model

The figure above implements a VoIP traffic to evaluate the performance of the integrated network during the handover process. The OMNeT++ modules used in the design include the following;

I. Serv: This module serves as a storage element because it stores messages (files) that have been generated by the traffic generator.

II. Gen: In OMNeT++, traffic is generated by the traffic generator, messages are simulated and sent in certain time intervals or conditions. This generated traffic represents VoIP traffic. Since we are modelling streaming traffic, the generator is made to transmit to the destination at certain and constant time intervals

III. fuzzySelAlg: This represents the Fuzzy inference system used for the RAT selection. This together with the roc, a weighting mechanism are the brain behind the overall RAT selection.

IV. Dest: this module is the sink type module which collects the traffic statistics that arrives at the destination.

V. RAT's: This comprises of the LTE, UMTS, Wi-Fi and WiMAX access technologies in this work. The radio access networks comprise of modules called the data buffer, it stores data or massages generated and sent during the simulation. When the file length gets to zero, it means that the message has been completely sent to the destination and the traffic generator can proceed sending another message (IP packet).

A mobile node (node 0) initiates a VoIP traffic session to another mobile node (node 1), the signalling protocols are used to create and setup the traffic session. Protocols like SIP, H.323 protocols setup the route and enable the data transmission via the IP network. The subscription of the mobile user determines whether the network grants any special services to the mobile user. The call authentication as earlier stated is done at the AAA server and a channel is opened to allow for the actual transmission of the media using a transport protocol. Other protocols such as media gateway protocol, routing protocols and transport protocols then handle control and routing once the route has been established for transmission of the data stream. Digitizing, sampling encoding and decoding of the signal is carried out at the user equipment and we have selected PCM quality as earlier stated in the OMNeT++ simulator.

6.3 Performance Results

When handover is performed, we must find a way to assess and compare the benefits with the cost. Improved network parameters which are observed over a given time interval can be described as the network benefits. It is difficult to assess the estimated gains in the perceived quality of service; however, this can be achieved by the introduction of a utility that accounts for the most relevant link parameters. A conventional method is to observe the traffic flow and compare it with an estimate of what would have occurred if the handover was not performed. Metrics such as available bandwidth, network jitter, delay, throughput, availability, packet loss are all key performance indices of a communication network system. OMNeT++ simulator provides an in-built support mechanism for the recording of simulation results through the output scalar and output vector files. The output vectors are time series data which records key performance indices such as end-to-end delays, link utilization, queueing times, module state, packet drop etc. On the other hand, the output scalar provides a summary computed during the simulation and this scalar result may be a number (real or integer), a statistical summary which has fields like minimum, maximum, mean, standard deviation, sum etc. Low latency times, reduced probability of dropped calls, close to zero loss of packet are output results which show the superior performance of the Fuzzy based handover technique in this dissertation. In other to avoid more complexities, we make assumptions such as no packet loss due to buffering overruns in any of the nodes.

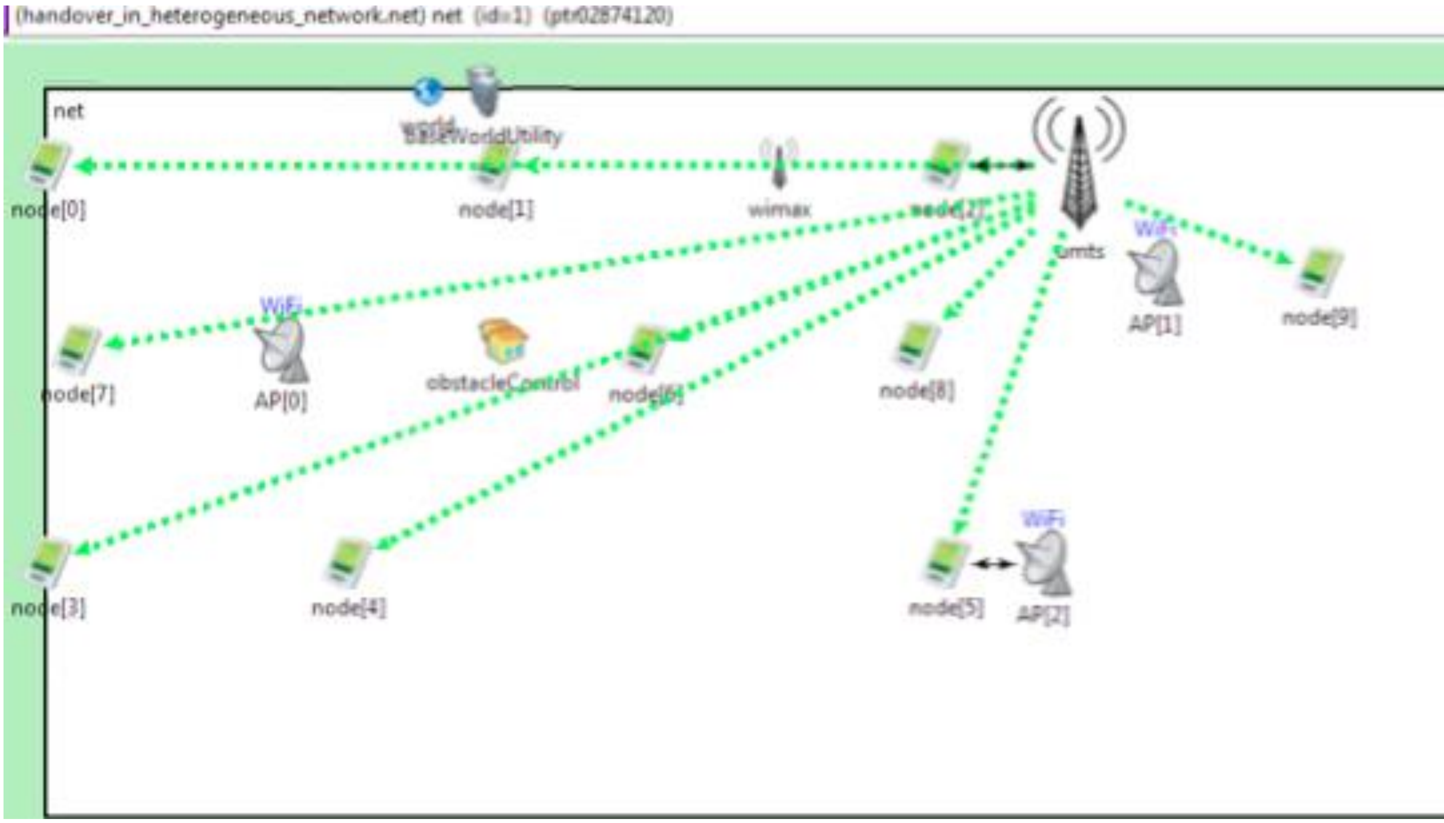

Figure 18.Heterogeneous network implementation using OMNeT++

The Fuzzy-based handover technique considers other parameter in order to determine the network which the mobile terminal connects to. One would think that since the RSS value of the access network closest to a mobile device will be stronger compared to that of another whose location is further away from that device, the closest will be its service station. However, the aggregation of other input parameters by the FIS explains why some mobile terminals close to an AP remain connected to the UMTS NodeB as shown in Figure 18 above. After launching the simulator, we activated an event log recording to provide us with inputs for the sequence chart during the length of simulation time i.e. as the mobile nodes switch from one access point to another in the course of its movement. At the end of the simulation runtime, the event log file in the result folder is shown in figure 19 below. We can see too much detail on the event log because every protocol layer has its own axis. We are concerned more importantly with the clustered portions which represent the actual handover process points for the mobile nodes and access points in the Network. To get a clearer picture in order to focus on the host and access points we filter to get the necessary information as shown in fig 20 and 21 respectively.

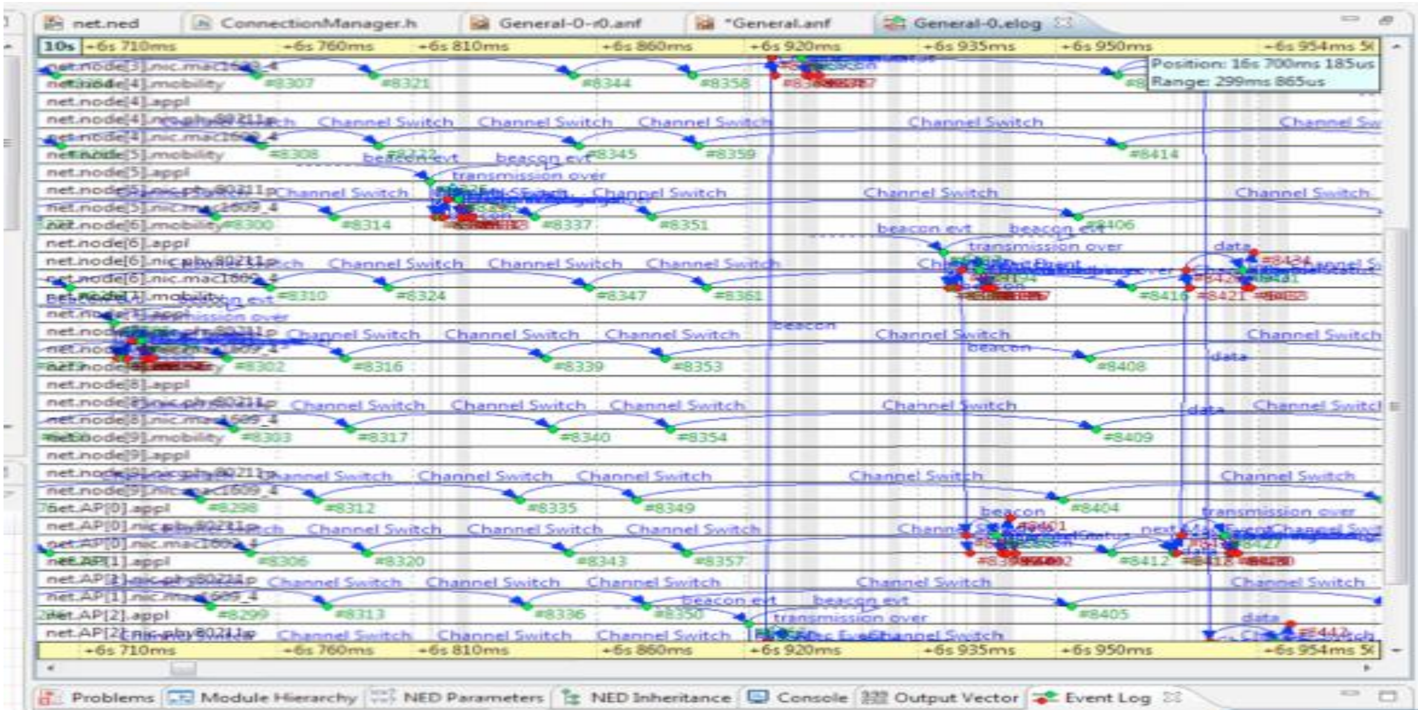

Figure 19.Event log

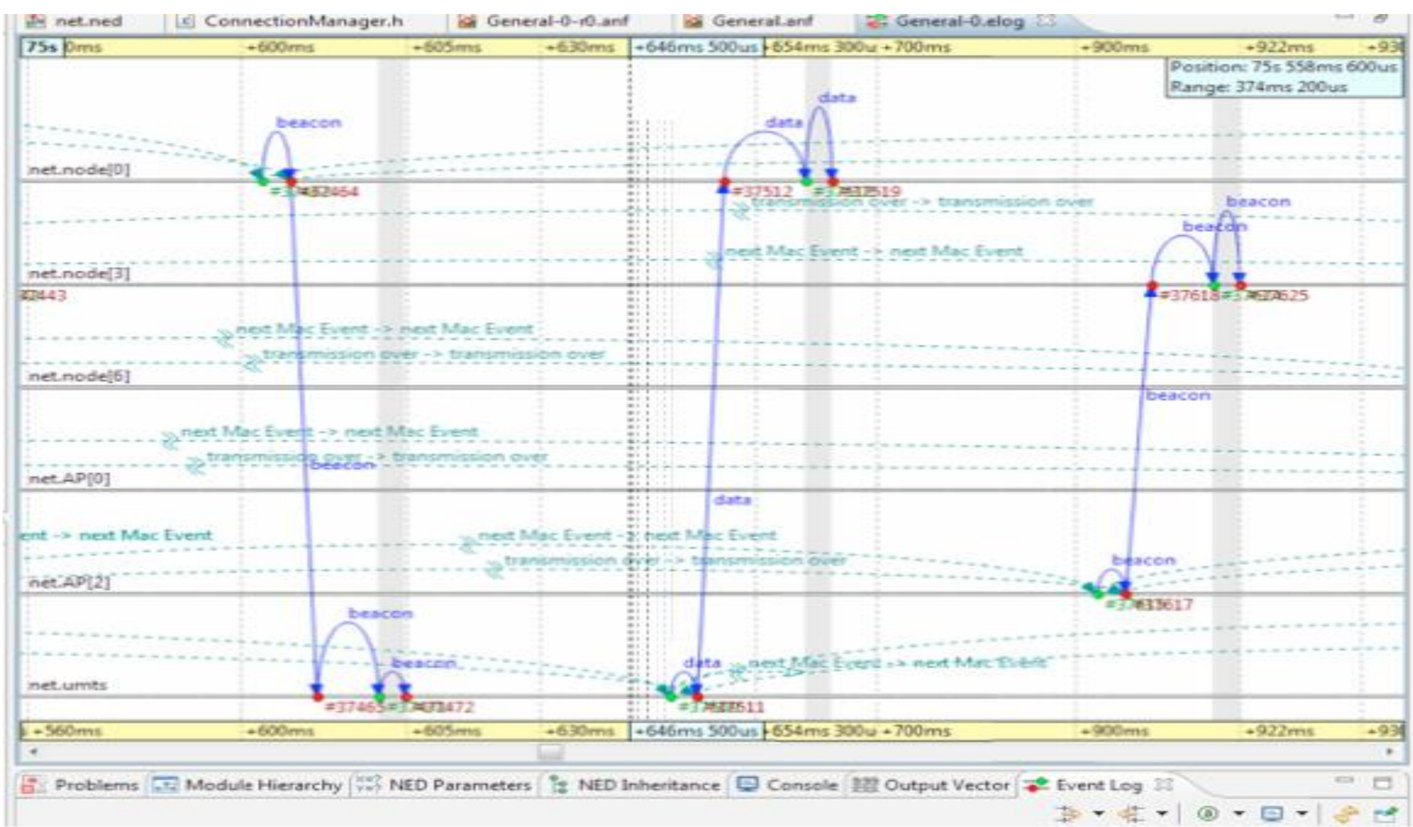

Figure 20.Beacon messages and intervals

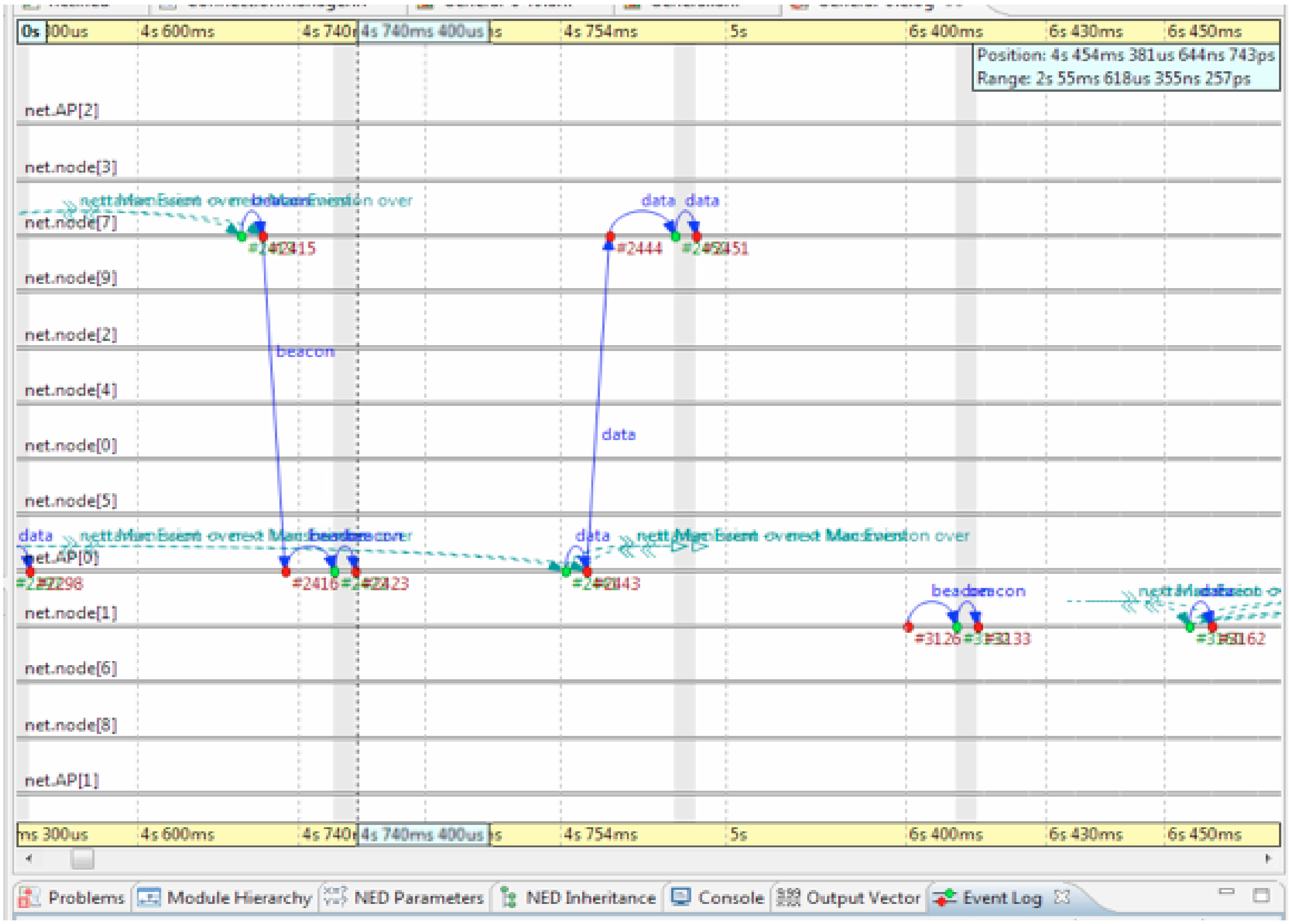

Figure 21.OMNeT++ Handover process View

Figure 19, 20 and 21 above shows the AP's, event numbers, message names, channel switching process times. It also captures the handover times for each of the mobile nodes as the transit the inter-network and initiate the handover procedures. Figure 21 shows captures the node 3, node 7, node 9 switching between AP(2) and AP(0). Other network statistics like the range, node position, time taken for the handover process are also displayed. Further below, the handover network statistics of a single node is analysed to show details captured by the simulator during the handover process. Figure 22 and 23. Details such as statistics of the number of dropped packets, received broadcast at the beacon intervals, transmitted packets, slots back off, busy time etc. shows the efficiency of the handover technique adopted.

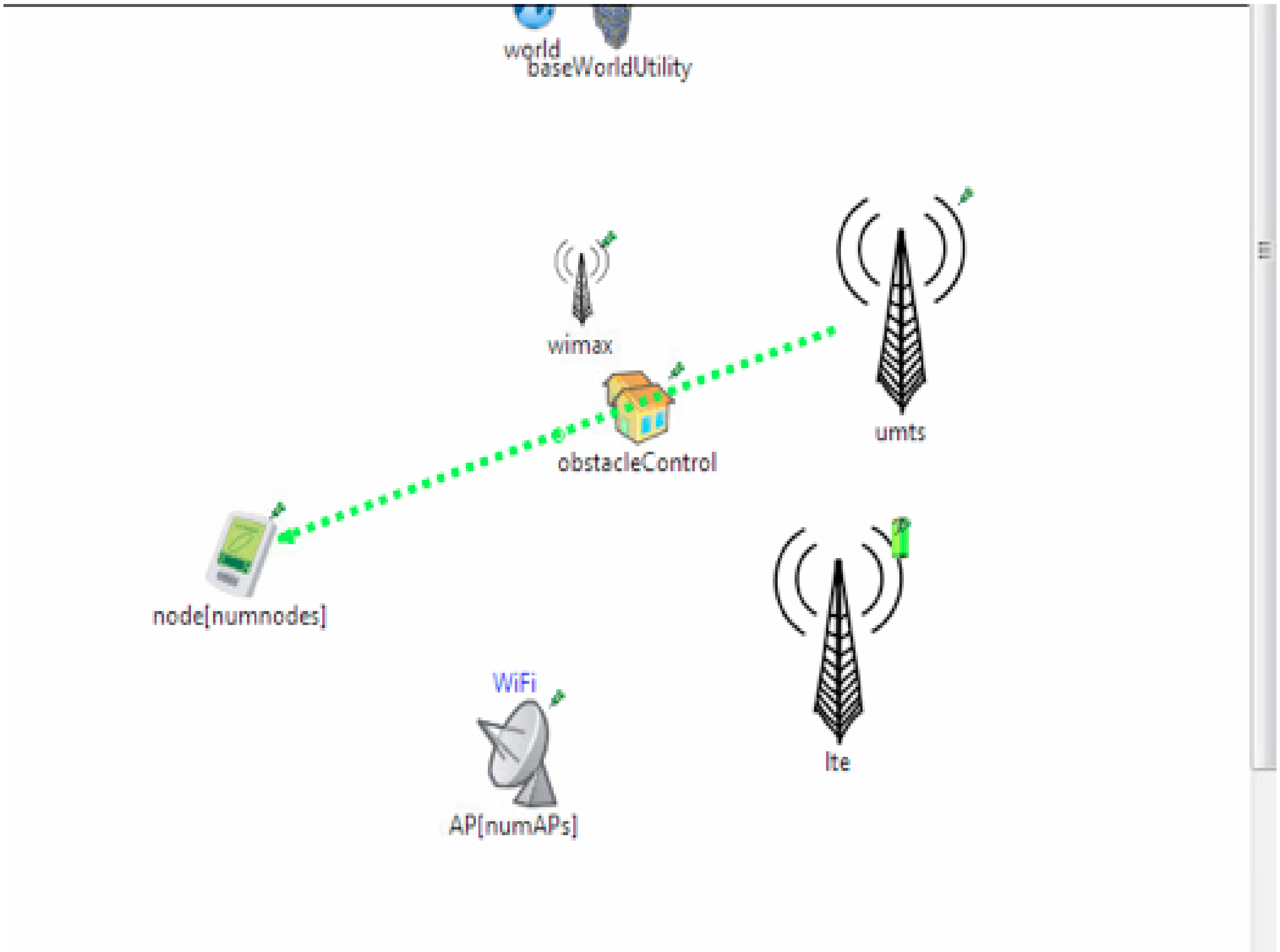

Figure 22.Single Terminal Node Scenario

For the purpose of this comparison, we look at the single case scenario. The integrated network is designed such that there is an overlap of the access technologies employed throughout the playground area. The statistics of the mobile node (0) is captured below during the handover of the terminal from the Wi-Fi to the UMTS network and It shows that node (0) records no packet loss or dropped packets during the transmission /transfer of service for the mobile node from the Wi-Fi to the UMTS network. This statistic is gotten at a random time during the simulation run at a constant speed by the mobile node (0). The system model for the simulation for the single node data as captured for figure 21 and figure 22 is further described in the next sub section.

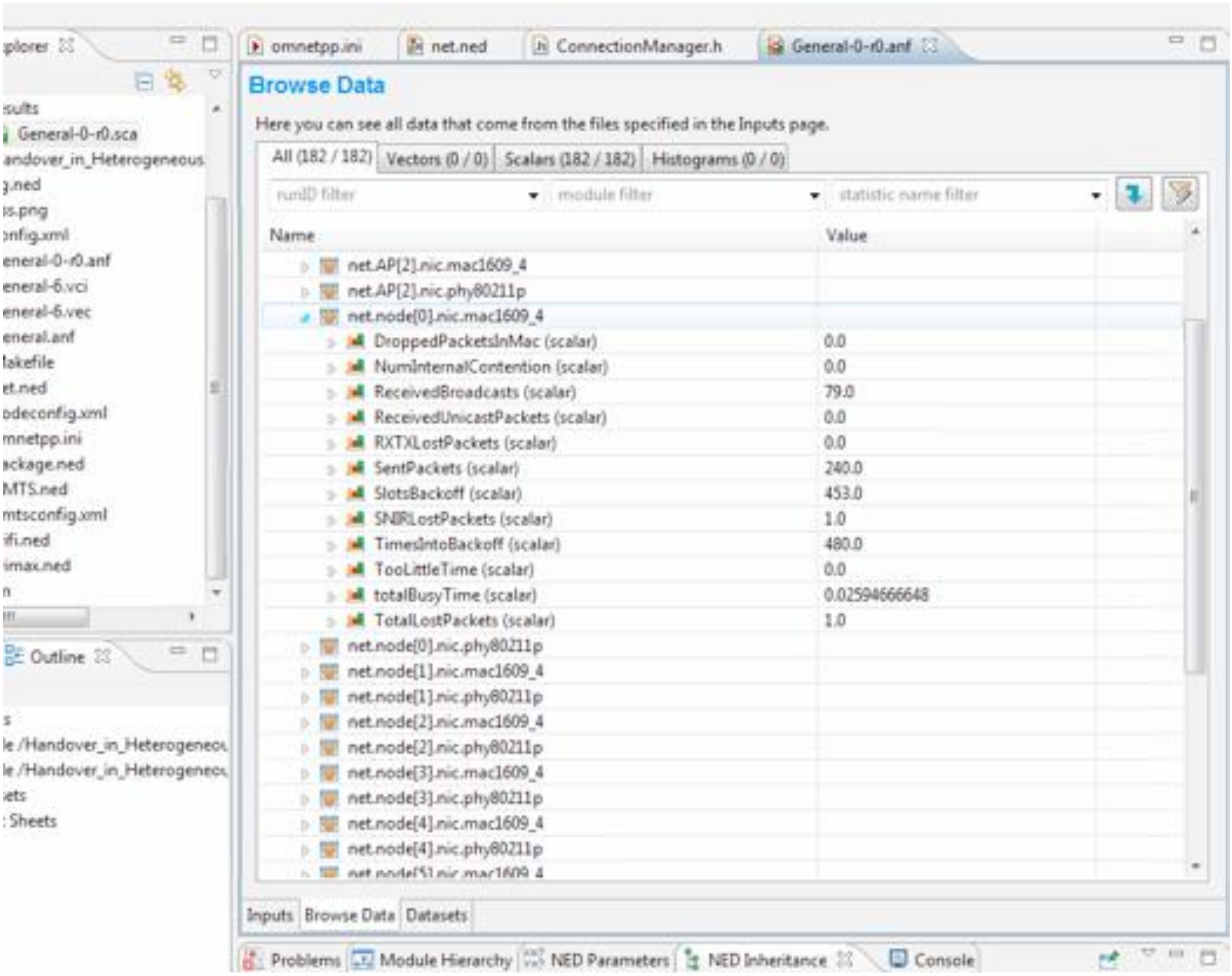

Figure 23.Mobile terminal (node 0) performance statistics.

6.4 System model for RSSI single criterion method.

The RSSI-based script defines two different thresholds, (TH_x^U, TH_x^L) upper and lower thresholds respectively and the instantaneous RSSI value recorded by the mobile terminal of the interface x is compared to these values. The generic subscript x is used to represent either of UMTS, Wi-Fi, LTE or WiMAX interface; i.e. TH_x^L is used to establish when the RSSI is insufficient to guarantee a good or stable connection while TH_x^U is to determine if the RSSI of the interface x is sufficient for a stable connection ($TH_x^U > TH_x^L$.). Hence, a situation where $RSSI_x <, TH_x^L$, handover is initiated and the connection on that interface is torn down. The establishment of the upper and lower thresholds is considered as the first step towards avoiding the ping pong effect. i.e. the continuous switch between the access networks likely to occur when the mobile terminal is around the border of any of the networks. In a situation where all networks are available, priority will be given to the WiMAX network since it is known to have a better data rate. Consider two base transmission stations BTS1 and BTS2 at a distance D meters, a mobile node moving away from BTS1 towards BTS2 at a certain speed will receive signal levels from the two BTS's as below

$$S_{rx1}(d) = K_1 - K_2 \log_{10}(d) + x_1(d) \; d \in (0, D) \text{ m} \tag{6.3.1}$$

$$S_{rx2}(d) = K_1 - K_2 \log_{10}(D - d) + x_1(d) \; d \in (0, D) \text{ m} \tag{6.3.2}$$

S_{rx1}, S_{rx2} are the received signal from BTS1, BTS2 and K_1, K_2 shadow fading due to the path loss. x_1, x_2represent two independent zero mean stationary Gaussian process. [15, 31]. With these relationships, handover then occurs from BTS1→ BTS2 or BTS2 →BTS1 depending on the RSSI compared to the threshold. A situation where the RSSI of both BTS's is below the minimum power value for which a call is possible then there is a call failure or call dropped expressed as

$$P_d = Prob(S_{rx1}(d) \le S_{r\,min} \; and \; S_{rx2}(d) \le S_{r\,min})$$

$$= Q(\frac{(\mu_1 - P_{r\,min})}{\sigma}) \times Q(\frac{(\mu_2 - P_{r\,min})}{\sigma}) \tag{6.3.3}$$

Q(x)- Q-Function. P($X \ge x$) $= Q$(x) X~$\mathcal{N}(0,1)$ and if $\mathcal{N}(\mu, \sigma)$ then

$$P(X \ge x) = Q(\frac{(\mu - x)}{\sigma}) = 1 - Q\left(\frac{(\mu - x)}{\sigma}\right) \tag{6.3.4}$$

We also ran a simulation script for RSSI-based handover algorithm in order to compare throughput performances of both techniques shown in figure 21. Network throughput is simply the average rate of messages delivered successfully through the communication channel (with the delivery channel either a logical or physical link).

$$throughput = \frac{total\ bytes\ sent \times 8}{time\ last\ packet\ was\ sent - time\ first\ packet\ was\ sent} \text{ (bits/sec)}$$

The simulation plots below clearly show that the Fuzzy based handover algorithm has better overall throughput compared to its traditional RSSI-based counterpart, we can also infer from the throughput that the average end-end delay for the Fuzzy based handover is lesser when compared to that of the RSSI-based.

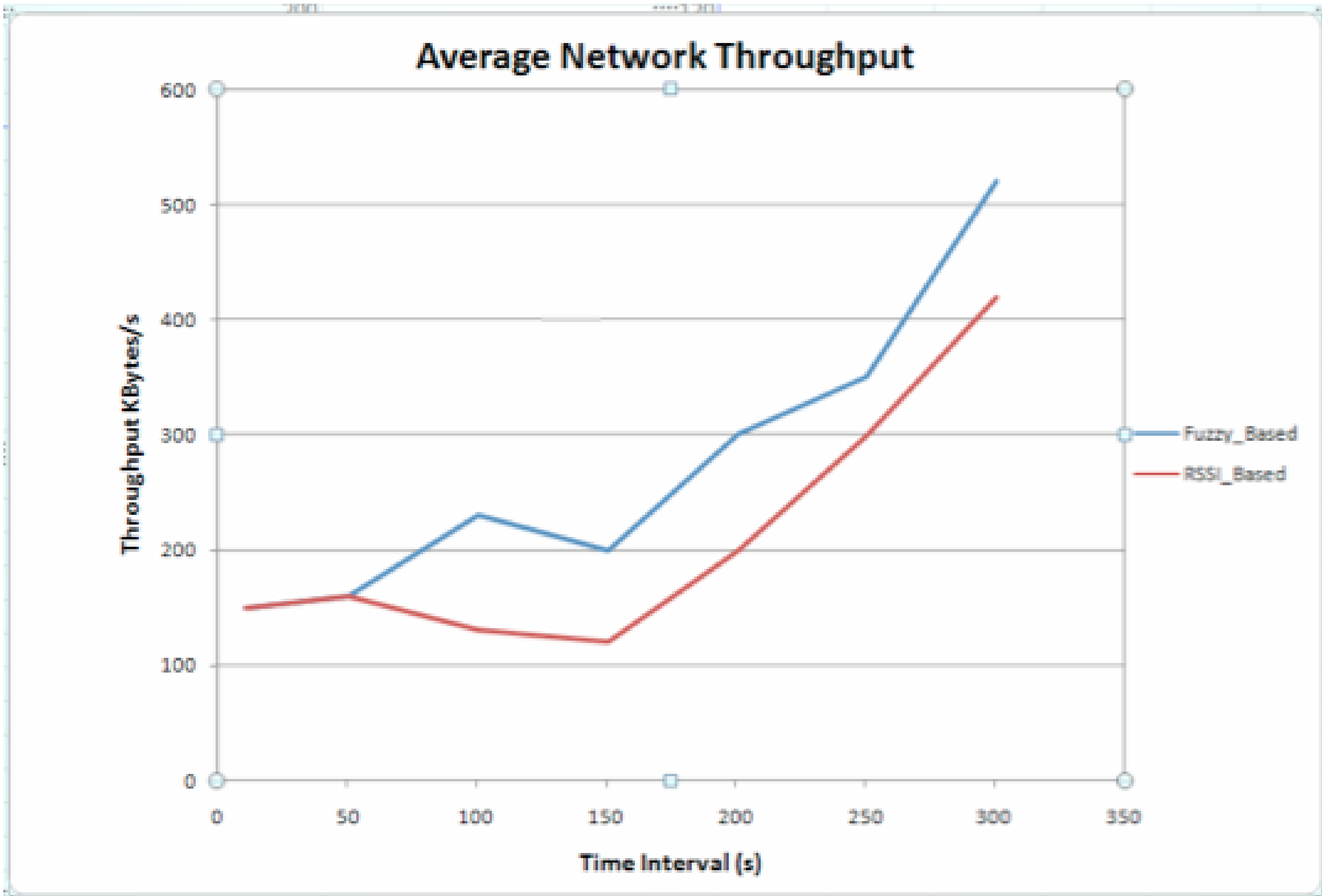

Figure 24.Throughput performance of Fuzzy-based/RSSI-based handover Algorithm

The above figure is obtained with the transmission of VoIP traffic for the two considered algorithms, it shows the elapsed time since the start of the run and the corresponding throughput in kbps. The throughput is the data rate successfully delivered over the communication channel, the throughput for the two techniques allows us to easily see the QOS. Up to about t=56 seconds, we observe that the two handover based algorithms display an approximately equal throughput but as the mobile device journeys further away the throughput relative to the handover process between the access technologies for the RSSI based algorithm further degrades when compared to that of the Fuzzy based mechanism. When the VHO manager selects a preferred network, the mobile terminal disconnects from its current serving network, in some instances the process is automatic (in cases where the remote authentication sever keeps the authentication state for a certain time period). As the mobile user continues to move, the network response time is depicted by the figure below. At the beginning of transition an initial value of zero is recorder as the latency, at a simulation time of about 15 to 20 seconds we see that the UMTS networks experiences a steady increase from 0.25s to 0.327s. In this same time interval, the Wi-Fi time delay is from 0.13s to approximately 0.17s and falls back to 0.13s. The WiMAX exhibits response of 0.06s with a maximum delay of 0.08s and later drops to 0.07s delay. The Wi-Fi network shows a better response time compared to the UMTS network which has wider coverage area while the WiMAX shows a better response time due to its higher data rates when compared to both, LTE due to its high data rates records no delay when the Fuzzy algorithm is apply to the nodes thereby providing a stable QoS for the running service of the traffic type. This simulation results show that the Fuzzy based technique considered the handover factor as recorded by all the access points that the mobile nodes receive signals from before selecting the best network.

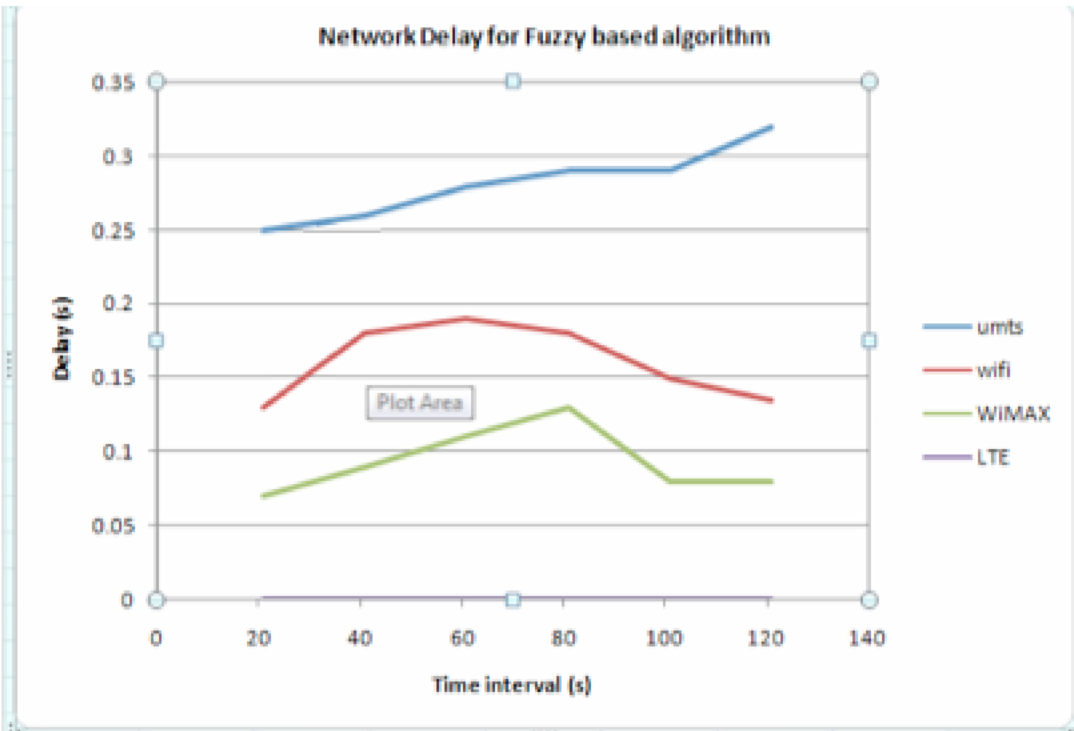

Figure 25.UMTS, WiMAX and Wi-Fi Delays.

From the plot of the delays experienced by the various networks, we see that the WiMAX network exhibits an average delay variation of about 0.08s, UMTS has a larger delay variation average of about 0.26s while the Wi-Fi exhibits a delay variation average of 0.14s. One of the most important performance metrics in VoIP analysis is Packet end-to-end delay, since it is known that voice streams should be transmitted timely. Packet-end-end delay is the time it takes for a packet to be transmitted from source to destination encompassing the other delays mentioned earlier. The ITU standard stipulates that the average end-to-end delay should be less than 150ms and the ideal end-to-end delay should be less than 50ms [45, 47]. As can be seen from the results displayed, the average delay in WiMAX appears much more steady as compared to that exhibited by UMTS and Wi-Fi showing a maximum average end-to-end delay of approximately around 0.9 seconds, which is less than the average delay in UMTS (<50%). From the simulation results, LTE and WiMAX network provides better VoIP services in terms of packet delay (end to end) and this can be directly related to their higher data rates and all-IP network type unlike UMTS which comprises of packet switched and circuit switched technologies. From the simulation results shown in the figure above, the LTE network has no delay. Beside its traditional characteristic of high data rates, the other assumptions earlier neglected is also responsible for its perfect performance in this simulation. In a UMTS network, VoIP call must go through a selection process to select either the packet or circuit switched technology, this adds to the overall end-to-end delay of that network. The back-off delay as earlier mentioned prevents the ping-pong effect. With the same network selection mechanism applied to all users, a situation where one access network is particularly excellent then it is expected that all the users will try to handover to that network within a short interval. Depending on the link capacity availability, link quality will drop considerably and again users will then be forced to perform handover again. A means of arriving or computing this back-off delay if to estimate benefits of handing over to preferred network compared to staying on the serving network. According to [42], the bigger this quality difference, the lesser the delay there is.

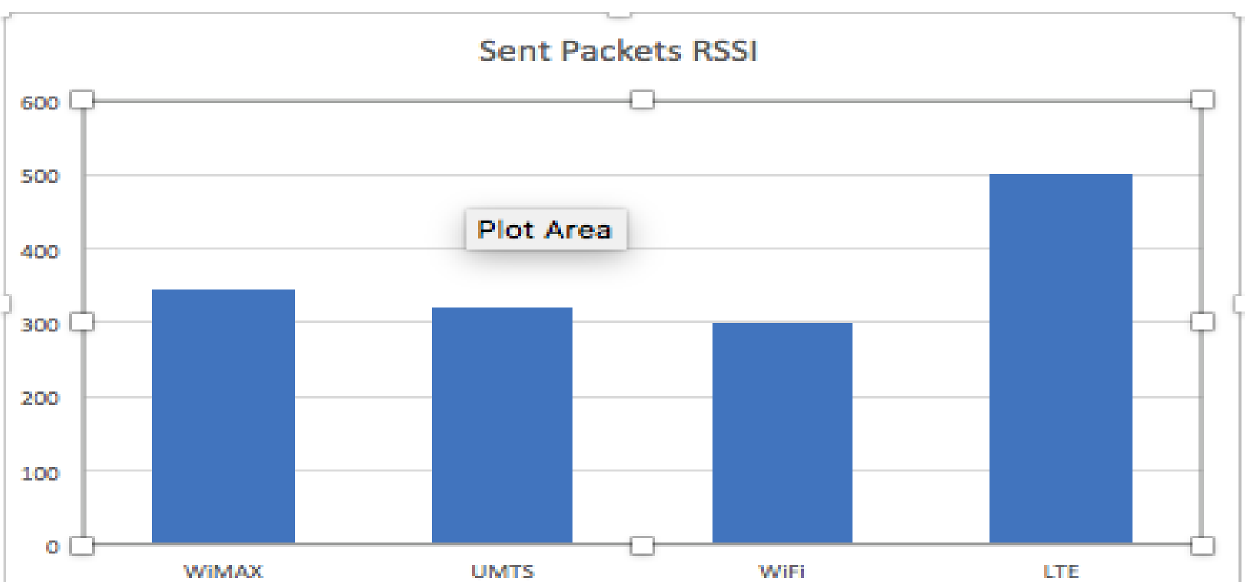

Figure 26.Sent Packet_NET Statistics for Node 1

The chart above shows the network statistics of the sent packets for different access technologies considered, it give us a view on the VoIP traffic behaviour of the network in terms of congestion before the multiple criteria is applied at the interface. The figure below shows the sent packet data for the same node with the multi criteria methodology applied. We can see that there is significant improvement in the data rates. An average of above 50% is recorded on the simulator for the best performing RAT.

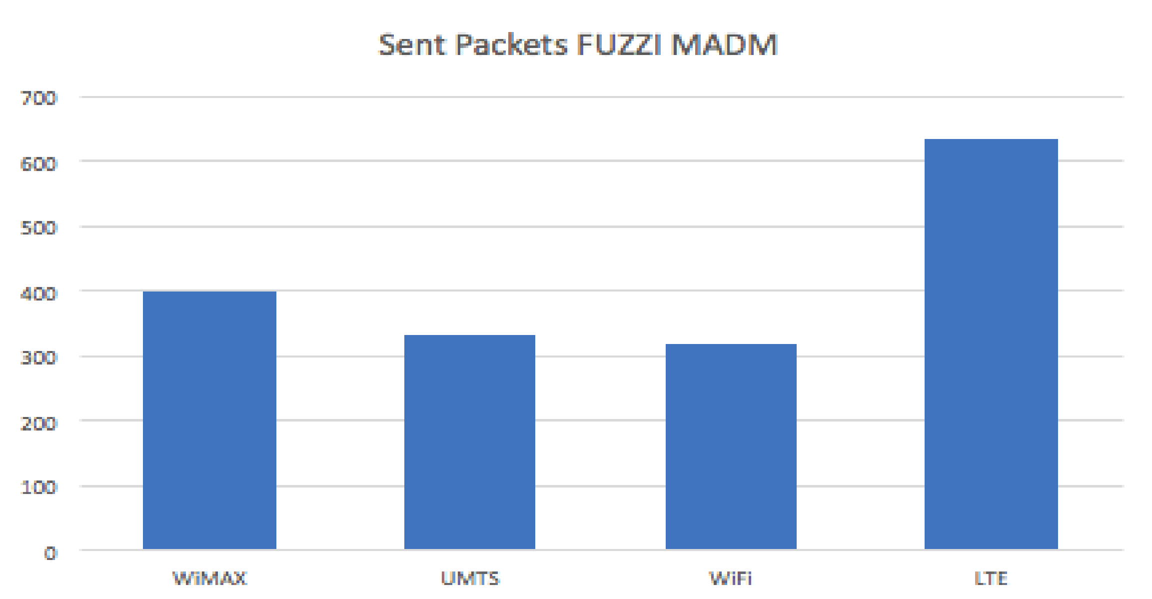

Figure 27.Sent Packet_Net Statistics for Node 1

We must bear in mind that the statistics is recorded at different distances from access points and different time variations in both cases. Figure 27 shows that when adopted, seamless VHDA greatly contribute to achieving the goal of maximizing the use of free data quota from the cellular system, selection of the most suitable network and successful handover recorded which in turn reduces data drop rates. When the Packet.Net statistics of before and after application is compared, we see that data sent for VoIP was less before application to the node interfaces. This variation from the two statistics can be used to arrive at the amount of data dropped for the running VoIP application. Figure 28 below shows a scattered plot of the activity of the ten mobile nodes used in the simulation at a chosen time and distance, the plot is a capture of the sent packet status of the mobile devices as they transit the network playground. Sent packet rates are important because they have direct consequences on the end-2-end delay which in turn affects the average throughput.

This is so because in cellular networks, packets are transmitted via several network links typically in segments then reconstruction takes place at the receiver end. Mechanisms like ARQ are employed to retransmit errors automatically, this is the main reason for the packet delay which ultimately influences the end-2-end delay mentioned above. During the simulation, we observed that packets arrive the destination in bursts and the inter-packet arrival time showed that these bursts or clusters arrived at a time difference of approximately 13ms interval. A plot of the individual inter-packet arrival time of each of the network will show the time differences of packet delivery in the different access technologies. The scattered plot for the bandwidth usage shows node 1 has highest usage of about 82kbps and each of nodes 0, 3, 6, 8 and 9 have the consistent average value of 51kbps.

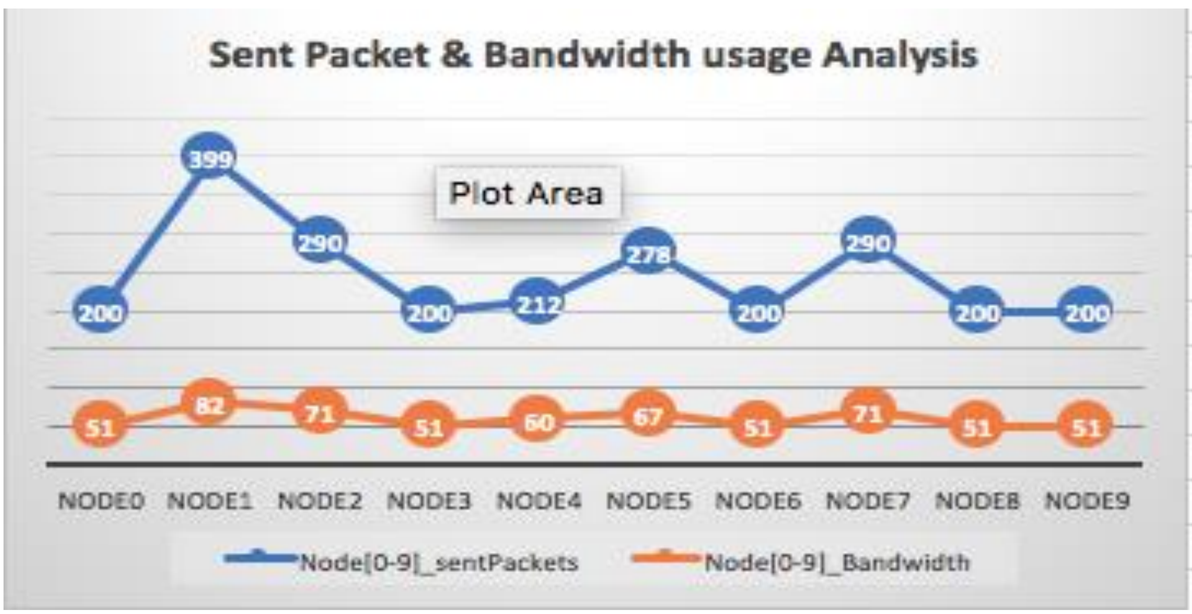

Figure 28.Nodes[0-9] SentPkT_Bandwidth Analysis

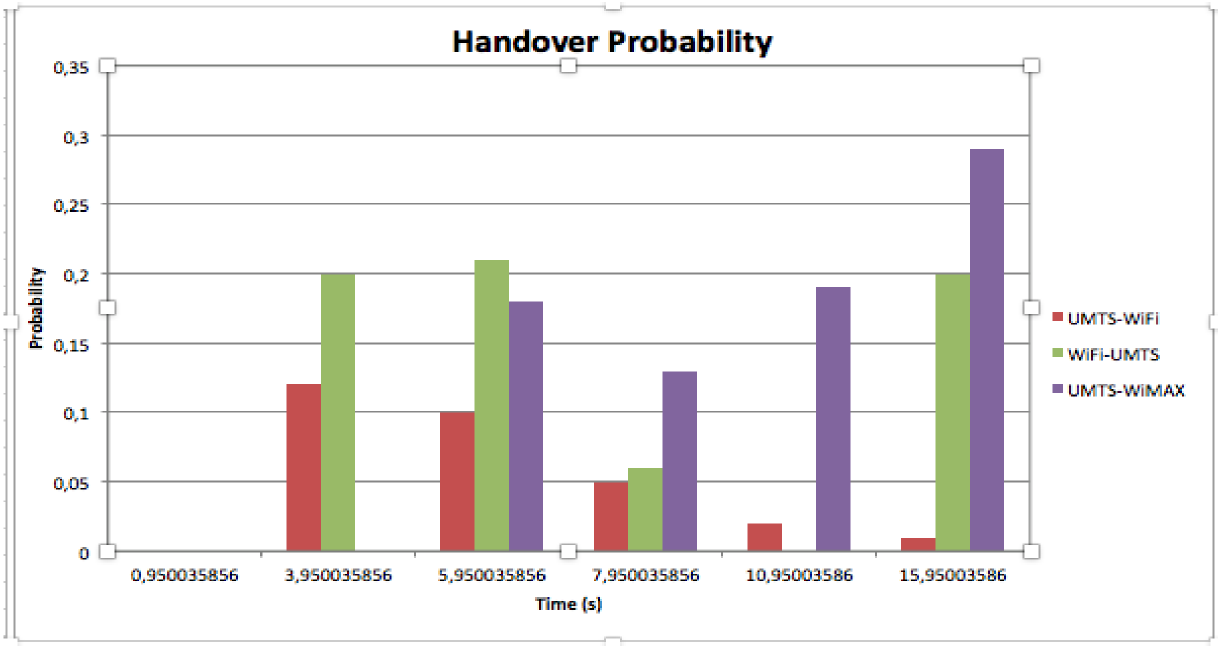

Figure 29.Handover Probability at random distances

The figure above shows the handover probabilities of the HetNet at different locations during the event simulation. It can be seen that from the beginning of our simulation observation, the access technology providing services to the mobile user measures good quality of service parameters (QOS). It shows that all the mobile user in that region serviced by the either of the three radio access technologies experience good quality of experience (QOE) thus there is no need for a handover procedure to be initiated during that time phase. As the event simulation runs and some of the network parameters change, there is a change in the throughput of the various networks and subsequent degradation of network services.

7 Conclusions

In the first chapter of this work, we gave an overview and summary of the objective of this work. The second chapter talked about related works in and highlighted fundamental principles involved in handover decisions, initiation and execution. The later part of that chapter also talked about the standards that have been stipulated for wireless communication networks. Chapter 3 described the design model and methodology employed where the simulation parameters and the parameters for the network selection criteria were defined. In the fourth chapter, the Fuzzy inference system and the procedures involved in obtaining the crisp Fuzzy output value was explained. It discusses all the parameters chosen as key matrices for the system, defines the respective universes of discourse and the linguistic variables of the Fuzzy system. Lastly we introduced the MADM to improve the network selection process. Chapter 5 described the characteristics, standards and architecture types of the RAT's of the heterogeneous network while chapter 6 gives a detailed description of the network simulator framework used. We also explained the choice of simulator, its network entities, functions and requirements. Lastly the chapter concludes with a display of the simulation results. Our results show that the Fuzzy MADM method of network selection performs better in selecting the best network when compared to the traditional RSSI based mechanism. Analysis for VoIP traffic model is represented through the charts of the handover probabilities of the access technologies (LTE, WLAN, WiMAX and UMTS) gotten from the simulation runs. The respective delays and throughput are represented in line charts showing the response times and throughputs as users move between different networks for the same VoIP traffic type. This analysis is done in the loose coupling internetwork architecture type.

This dissertation has attempted to analyse the multi criterion and single criteria basis of vertical handover techniques by implementing the fuzzy based technique. The simulation results show that intelligent handover decision methods are essential to selection in heterogeneous wireless mobile networks. We can see that Fuzzy logic together with the decision making methods of network selection improves the accuracy. This results and a thorough study of works of already existing VHD algorithms that implement Fuzzy is cost effective and useful. A wide range of network characteristics motivates implementation of a multi-criteria-based handover decision algorithm together with ROC selection process that presents a QoS aware handover decision mechanism with LTE, WiMAX, Wi-Fi and UMTS supporting VoIP traffic. Our results showed the delay during handover is a critical parameter and LTE, WiMAX networks outscores Wi-Fi and UMTS with LTE technology performing best in this handover simulation procedure.

7.1 Future Works

The internetworking architecture employed in the integration of the radio access technologies offers a joint or shared interface for the exchange of information (AAA server), although this guarantees independence, it however causes high latency during handovers [49]. This same work should be extended to include the tight coupling heterogeneous network integration architecture using the same network parameters adopted for this work for comparison. The mobile terminals should not be restricted to a linear trajectory since in practice, mobile nodes move in an unpredictable random manner and at different speeds. The fading channel characteristics can be better fine-tuned as the standards on the simulator framework were not altered in this work. Areas that can be considered for future work include load balancing on the interfaces and mobile IP in relation to this work and a simulation with consideration for gateway relocation and channel reservation. A good number of VHD algorithms currently proposed still lack a enough details for implementation, this area is still very challenging as the main difficulty of designing an algorithm that truly utilizes all the important/useful wide range conditions still lingers. A comprehensive consideration of wider network parameters should be investigated in order to have an algorithm suitable for wide ranging conditions. Future work will focus on further enhancement of intelligence of network selection mechanisms, especially when mobility-related decision parameters (e.g., velocity, direction of movement, distance of UE from BS, etc.) are considered and carrying out a sensitivity analysis to ascertain the degree of influence that the various selection parameters have on the efficiency of handover in general.

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Appendix A

The code below is part of the OMNeT++ code for the network simulation using the MiXiM framework as described in the project work.

```
[General]
network = net
sim-time-limit = 200s
num-rngs = 3
debug-on-errors = true
**.coreDebug = false
**.playgroundSizeX = 10000m
**.playgroundSizeY = 10000m
**.playgroundSizeZ = 0
**.useTorus = true
**.use2D = true
*.node[*].connectionManager.sendDirect = false
*.AP[*].connectionManager1.sendDirect = false
*.wimax.connectionManager2.sendDirect = false
*.umts.connectionManager3.sendDirect = false
**.numnodes = 10
**.numAPs = 3
**.scalar-recording = true
**.vector-recording = true
output-scalar-file = ${resultdir}/${configname}-0-r${repetition}.sca
output-vector-file = ${resultdir}/${configname}-0-r${repetition}.vec
```

*.wimax.connectionManager2.pMax = 30mW

*.wimax.connectionManager2.sat = -94dBm

*.wimax.connectionManager2.alpha = 1.0

*.wimax.connectionManager2.carrierFrequency = 5.890e9 Hz

*.umts.connectionManager3.pMax = 30mW

*.umts.connectionManager3.rssi = -76dBm

*.umts.connectionManager3.bandwidth = 56 Mbps

*.umts.connectionManager3.alpha = 1.8

*.umts.connectionManager3.carrierFrequency = 5.890e9 Hz

*.node[*].connectionManager.pMax = 20mW

*.node[*].connectionManager.rssi = -94dBm

*.node[*].connectionManager.bandwidth = 56 Mbps

*.node[*].connectionManager.alpha = 2.0

*.node[*].connectionManager.carrierFrequency = 5.890e9 Hz

*.AP[*].connectionManager1.pMax = 20mW

*.AP[*].connectionManager1.rssi = -94dBm

*.AP[*].connectionManager1.bandwidth = 56 Mbps

*.AP[*].connectionManager1.alpha = 2.0

*.AP[*].connectionManager1.carrierFrequency = 5.890e9 Hz