بسم الله الرحمن الرحيم


# SUDAN UNIVERSITY OF SCIENCE AND TECHNOLOGY
## COLLEGE OF ENGINEERING
## ELECTRONICS ENGINEERING DEPARTMENT


# Optimal Network Selection from Heterogeneous Radio Networks

# اختيار الشبكة الامثل بين الشبكات الراديوية غير المتجانسة


**Prepared by:**

**Islam Ahmed Babiker Mohamed**

**Supervisor:**

**Dr. Fath Elrahman Ismael Khalifa Ahmed**


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# Abstract

Fourth generation (4G) wireless networks are expected to support mechanisms for tight integration and cooperation of divergent access network technologies. Radio network selection is the mechanism which decides how to select the most suitable RAT based on the discovered accesses, QoS constraints, operator policies, user preferences and available system capacity and utilization. In such networks of heterogeneous nature, roaming users will experience frequent handovers across network boundaries and also the user who wants to request for services. Thus, optimizing the selection process is an important issue of research to select the best network, ensure seamless roaming and efficient resource usage over dissimilar networks, so intelligent algorithms need to be used extensively. This thesis presents a vertical handover decision (VHD) scheme for optimizing the efficiency of vertical handover processes in the Fourth Generation (4G) heterogeneous wireless networks where increase the throughput and the data rate for the user. Tow networks are considered, LTE and WiMax. The handover between them will execute according to the RSS, bandwidth and SNR, this compare to the handover according to the RSS only. The results show that the throughput and the data rate increase when we use additional parameters to the RSS.

# مستخلص

من المتوقع أن يجمع الجيل الرابع للاتصالات عدد من التقنيات المختلفة، ويدعم التعامل والتعاون بين هذه التقنيات. اختيار الشبكة هي الآلية التي تحدد اختيار التقنية الأنسب من بين التقنيات المختلفة بناءً على جودة الخدمة، سياسات المشغل، المشترك نفسه والسعة المتاحة وإمكانية الاستفادة منها. في الشبكات ذات الطبيعة غير المتجانسة ستتم عملية الاختيار للشبكة للمشتركين المنتقلين بين حدود التقنيات المختلفة وأيضا للمشترك الذي يطلب الوصول للشبكة. لذا فان عملية تحسين الاختيار من القضايا المهمة للباحثين لتحديد أفضل شبكة، وضمان التجوال السلس واستخدام الموارد بكفاءة لذلك نحتاج لخوارزميات ذكية ليتم استخدامها. يقدم هذا البحث آلية التسليم العمودي لتحسين كفاءة عملية التسليم في الجيل الرابع للشبكات غير المتجانسة لزيادة الإنتاجية ومعدل البيانات للمستخدم. هنا ستتم عملية الاختيار بين شبكتين (شبكات التطور طويل الأمد و واي ماكس) وفقاً لقوة الإشارة المستقبلة، عرض النطاق ونسبة الإشارة للضجيج بالمقارنة مع عملية الاختيار في حال استخدام قوة الإشارة المستقبلة فقط. ستوضح النتائج زيادة الإنتاجية وزيادة معدل البيانات  عند استخدام معاملات إضافية.

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# List of Abbreviations

| | |
|---|---|
| HetNet | Heterogeneous Network |
| 3G | Third Generation |
| LTE | Long Term Evolution |
| WiMax | Worldwide interoperability for Microwave Access |
| QoS | Quality of Service |
| RAT | Radio Access Technology |
| SNR | Signal to Noise Ratio |
| 1G | First Generation |
| NMTS | Nordic Mobile Telephone System |
| AMPS | Advanced Mobile Phone System |
| TACS | Total Access Communications System |
| 2G | Second Generation |
| TDMA | Time Division Multiple Access |
| CDMA | Code Division Multiple Access |
| GSM | Global System for Mobile Communications |
| iDEN | integrated Digital Enhanced Network |
| PDC | Personal Digital Cellular |
| 2.5G | Second and a Half Generation |

| | |
|---|---|
| GPRS | General Packet Radio Service |
| EDGE | Enhanced Data rates for GSM Evolution |
| WCDMA | Wideband Code Division Multiple Access |
| TD-SCDMA | Time Division Synchronous Code Division Multiple Access |
| HSPA+ | evolved High Speed Packet Access |
| UMTS | Universal Mobile Telecommunications System |
| BS | Base Station |
| 4G | Fourth Generation |
| TACS | Total Access Communications Systems |
| FDMA | Frequency Division Multiple Access |
| DAMPS | Digital Advanced Mobile Phone System |
| SMS | Short Message Service |
| ETSI | European Telecommunications Standards Institute |
| BTS | Base Transceiver Station |
| BSC | Base Station Controller |
| BSS | Base Station Subsystem |
| MSC | Mobile Switching Center |
| HLR | Home Location Register |

| | |
|---|---|
| VLR | Visitor Location Register |
| AUC | Authentication Center |
| EIR | Equipment Identity Register |
| NSS | Network Station Subsystem |
| HSCSD | High Speed Circuit Switched Data |
| IP | Internet Protocol |
| SGPRS | Serving GPRS Support Node |
| GGPRS | Gateway GPRS Support Node |
| MS | Mobile Stations |
| UTRAN | Universal Terrestrial Radio Access Network |
| FDD | Frequency Division Duplex |
| TDD | Time Division Duplex |
| 3GPP | Third Generation Partnership Project |
| ITU | International Telecommunication Union |
| IMT-2000 | International Mobile Telecommunication for the year 2000 |
| HSDPA | High Speed Downlink Packet Access |
| IS-95 | Interim Standard 95 |
| EVDO | Evolution Data Optimized |

| | |
|---|---|
| OFDM | Orthogonal Frequency Division Multiplexing |
| Mbps | Mega bit per second |
| GHz | Giga Hertz |
| MHZ | Mega Hertz |
| KHz | Kilo Hertz |
| IEEE | Institute of  Electrical and Electronics engineers |
| MAC | Medium Access Control |
| QAM | Quadrature Amplitude Modulation |
| eNB | evolved Node B |
| RSS | Received Signal Strength |
| VHD | Vertical Handover |
| WLAN | Wireless Local Area Network |
| ASST | Application Signal Strength Threshold |
| SINR | Signal to Interference plus Noise Ratio |
| ANN | Artificial Neural Networks |
| VHM | Vertical Handoff Manager |
| ID | Identification |
| MT | Mobile Terminal |

| | |
|---|---|
| dB | Decibel |
| MSE | Mean Square Error |
| MMSE | Minimum Mean Square Error |
| SINR | Signal to Interference Noise Ratio |
| BW | Bandwidth |
| QPSK | Quadrature Phase Shift Keying |
| QAM | Quadrature Amplitude Modulation |
| MI | Mutual Information |
| PHY | Physical Layer |
| bps | bit per second |
| PER | Packet Error Rate |
| BER | Bit Error Rate |

# List of Symbols

| | |
|---|---|
| $Wav$ | The window size of a slope estimator |
| $\overline{RSS}[k]$ | The calculated average of RSS at time instant $k$ |
| EL $[k]$ | The lifetime metric |
| $S[K]$ | RSS change rate |
| $\gamma_{AP}$ | The SINR at the mobile terminal when associated with WLAN |
| $\gamma_{BS}$ | The SINR at the mobile terminal when associated with WCDMA |
| $W_{AP}$ | The carrier bandwidths of WLAN links |
| $W_{BS}$ | The carrier bandwidths of WCDMA links |
| $\Gamma$ | The dB gap between the uncoded Quadrature Amplitude Modulation (QAM) and channel capacity |
| $Q_i$ | The quality factor of network i |
| $C_i$ | The cost of service |
| $S_i$ | Security |
| $P_i$ | Power consumption |
| $D_i$ | Network condition |
| $F_i$ | Network performance |

| | |
|---|---|
| $\omega_c$ | The weight of cost |
| $\omega_s$ | The weight of security |
| $\omega_p$ | The weight of power consumption |
| $\omega_d$ | The weight of network condition |
| $\omega_f$ | The weight of network performance |
| $P_r$ | Received power |
| $P_t$ | Transmit power |
| $d_0$ | A reference distance for the antenna far-field |
| $\gamma$ | The path loss exponent |
| $s(t)$ | The transmitted signal |
| $n(t)$ | The noise |
| $PI$ | The average power of the interference |
| $E_b$ | The signal energy per bit |
| $E_s$ | The signal energy per symbol |
| $T_s$ | The symbol time |
| $T_b$ | The bit time |

# CHAPTER ONE

# INTRODUCTION

# Chapter One

# Introduction

## 1.1 Preface

Recently the technology world became different and developed quickly so the next generation of the wireless telecommunication systems will involve the integration, diverse and complementary cellular and wireless technologies. These networks called heterogeneous networks (HetNet) [1].

Heterogeneous networks defined as a combination of large and small cells (macro, pico, fimto) with different radio technologies (3G, LTE, WiMax) all working together to provide the best coverage and optimal capacity [2]. Heterogeneous networks pose many challenges in several areas. At the lowest levels, many new access technologies for example 3G, WiMax and LTE will be supported on HetNet devices. Another key issue to be addressed is the Quality of Service (QoS). This because different wireless networks characterized by a variable QoS that affects the ability of the network services to achieve efficient performance since these systems must respond to changes in QoS in the available channels. The main challenge of the HetNet is the mechanisms of deciding which network is the most suitable for each user per time for every service in order to satisfy customer needs. This requires not only to achieve seamless mobility, but also to support quality of service (QoS) enhancement and load balancing [3,4]. In HetNet there are two approaches of network selection scheme, one is network driven selections and the other is user driven selections. In the network driven approach, the networks make decisions for selection while in the user driven approach the selection decision is made by means of user side. When there are many networks operating in a particular coverage area it will be difficult for users to select the suitable network to connect and how to authenticate with. So there is a need to have mechanisms for users to dedicate the suitable network to connect to. The mechanisms are executed in two cases, when a user requests for a new service or when there is a handover request [6].

This project proposes an algorithm for network discovery and selection in a heterogeneous network. The proposed algorithm has been implemented in Matlab and its performance has been evaluated by simulations. There are many algorithms for selecting in heterogeneous networks, most of them depend on one parameter like the type of service, bandwidth or received signal strength, but in this research, the proposed algorithm includes an extended set of selection parameters that refer to key performance indicators to improve the selection criteria and satisfy the user's needs.

## 1.2 Problem Statement

The challenge of the HetNet is how to select and access the appropriate network at a specific time. At the existence of many networks in a coverage area, the user must select the proper one to access, so it is important to find most suitable mechanism to perform network discovery and selection in heterogeneous networks, find the best network available and seamlessly handover to selected network without any interruption to the users.

## 1.3 Proposed Solution

There are many proposed algorithms for network selection in HetNet, these algorithms don't guarantee the required QoS for all calls, have limitations and don't provide a complete solution for network selection problems. So there is a need for an intelligent approach to select the radio access technology.

The proposed solution is to create an enhanced algorithm for network discovery and selection in HetNet according to a set of parameters. The algorithm will be evaluated through simulation results for a reference scenario including several radio access networks. The simulation results will show how the considered shall influence the network discovery and selection mechanism, increase the throughput and data rate.

## 1.4 Objectives

The main objectives of this research are to obtain the following:

1- Design an optimal algorithm for network selection in HetNet.
2- Increase the throughput;
3- Increase data rate.

## 1.5 Methodology

This research evaluated network discovery and selection in HetNet. The proposed algorithm that used to take the decision about which network to select depended on received signal strength (RSS), mobility aspects (speed and direction), bandwidth availability at the target network and signal to noise ratio SNR. According to the above parameters, the proposed networks arranged in a list and then selected the best network for the user. To verify the algorithm by using Matlab tools for simulation. The networks considered for the simulation, assumed a scenario of LTE and WiMax. The results were in figures to show the increasing of throughput and data rate which increase the QoS and users satisfaction.

## 1.6 Thesis Outlines

This research contains five chapters. Chapter one includes an introduction about the topic, the problem statement, the proposed solution and the methodology. Chapter two gives an overview about the evolution of the wireless networks and heterogeneous wireless networks and related works of the topics. Chapter three discusses the simulation of the proposed algorithm. Chapter four contains the results of the simulation and the discussion and chapter five presents the conclusion and recommendations.

# CHAPTER TWO

# LITERATURE REVIEW

# Chapter Two

# Literature Review

## 2.1 Wireless Telecommunication Technologies Evolution

Today, communication technologies have become an integral part of people's daily life and the wireless communication market has grown rapidly. Driven by the increasing demands of the market, wireless communication technologies have evolved from the first to the fourth generation.

Future wireless networks are expected to provide users with convenient global information access capabilities and personalized multimedia wireless communication services. Growing interest in heterogeneous networks is leading to a convergence of various wireless network technologies. Therefore there is a need to have mechanisms in place to decide which network is the most suitable for each user at each moment in time for every application that the user requires. This mechanism is called "network selection" or "access selection". It is executed in three cases, namely when a user makes initial access to a network, when the user makes a new service request and when there is a handover request. Regarding each of these cases, the network selection has different objectives and it uses different criteria to make its decisions [10].

In the next figure and paragraphs, there are a brief about the evolution of the wireless communications.

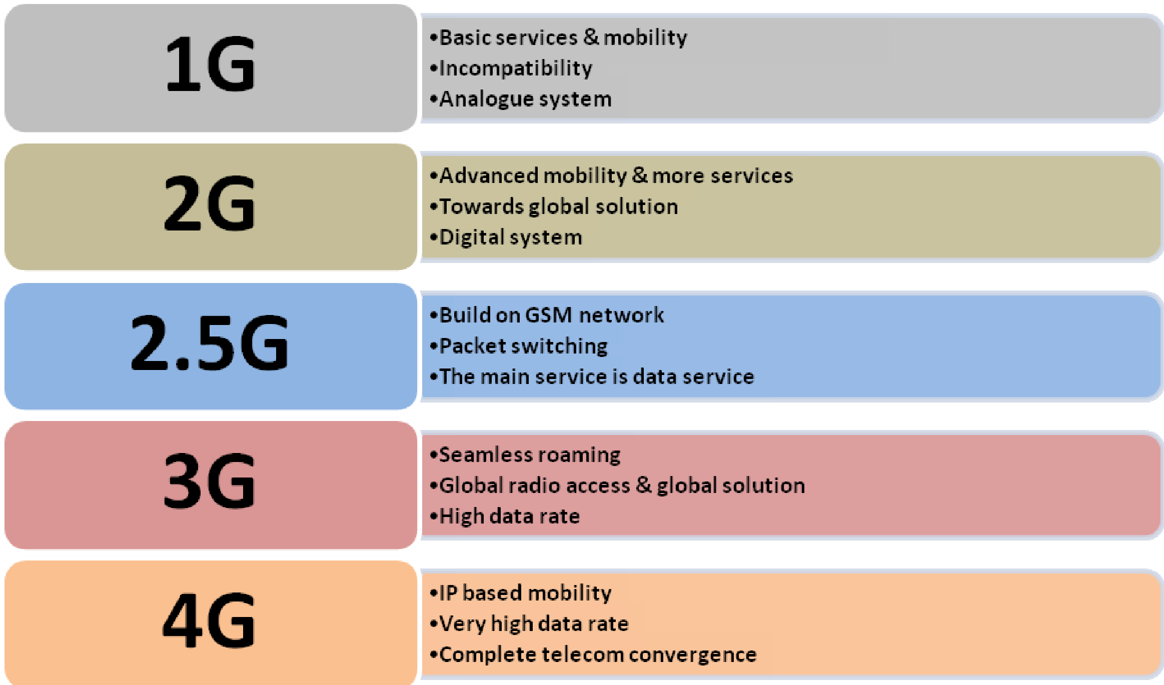


**Figure 2.1:** wireless telecommunication technologies evolution

### 2.1.1 First Generation (1G)

1G refers to the first generation of wireless telecommunication technology. A set of wireless standards developed in the 1980′s, which featured mobile radio telephones and such technologies as Nordic Mobile Telephone System (NMTS), Advanced Mobile Telephone System (AMTS), and Total Access Communications Systems (TACS). 1G wireless networks used analog radio signals. Through 1G, a voice call gets modulated to a higher frequency of about 150MHz and up as it is transmitted between radio towers. This is done using a technique called Frequency Division Multiple Access (FDMA).

In terms of overall connection quality, 1G compares unfavorably to its successors. It has low capacity, unreliable handoff, poor voice links, and no security at all since voice calls were played back in radio towers, making these calls susceptible to unwanted eavesdropping by third parties [6,31].

### 2.1.2 Second Generation (2G)

2G technologies are based on digital system using time division multiple access (TDMA) or code division multiple access (CDMA), the 2G standards may include the following: integrated Digital Enhanced Network (iDEN), Global System for Mobile communications (GSM) used worldwide, Digital Advanced Mobile Phone System (D-AMPS) is used in North and South America and Personal Digital Cellular (PDC) is used in Japan.

2G telecom networks were commercially launched in 1991 on the GSM standard in Finland. The 2G systems were found to be considerably more efficient on the spectrum, allowing far greater mobile phone penetration levels, moreover the phone conversations were digitally encrypted.

2G makes use of a CODEC or compression-decompression algorithm for compressing and to multiplex digital voice data. Using this technology, it is possible for a 2G network to bundle more calls per amount of bandwidth. As the data is transmitted through digital signals, 2G also offers extra services such as SMS and e-mail. Moreover the battery takes longer due to the lower-powered radio signals. Digital voice encoding, offering a feature of error checking, also improves the sound quality by reducing dynamic and lowering the noise floor [7,32].

#### 2.1.2.1 Global System for Mobile Communications (GSM)

Global System for Mobile communications (GSM) is an open, digital cellular technology used for transmitting mobile voice and data services. In 1989, the GSM working party was taken over by ETSI, and since 1991 has been called the Group Special Mobile. Today the abbreviation GSM stands for Global System for Mobile Communication, thereby underlining its claim as a worldwide standard.

The GSM meets certain business objectives such as support for international roaming, good speech quality, ability to support handheld terminals, low terminal and service cost, spectral efficiency, support for a range of new services and facilities and ISDN compatibility.

GSM uses a combination of FDMA and TDMA. GSM runs over different frequency bands 800 MHz, 1800MHz, 900MHz and 1900MHz. The forward and reverse frequency bands are generally spilt into channels each with 200 KHz wide which divide into eight 25 kHz time slots. Data can be transmitting through time slot which contain user and signaling information. GSM has different types of logical channels and they are separated as traffic channels and control channels. The traffic channels to transmit user data and the control channels for signal information by BTS to all mobile stations.

In the GSM the coverage area divides into small areas called cells. The four main cells that make up a GSM network are called macro, micro, pico and femto. Outdoor coverage is typically provided by macro and micro cells, while indoor coverage is usually provided by the pico and femto cells. Each cell in GSM has its own base transceiver station (BTS). Several BTSs together are controlled by one base station controller (BSC). The BTSs and BSCs form base station subsystem (BSS). The combined traffic of the mobile stations in their respective cells is routed through mobile switching center (MSC). There are several database for call control and network management: the home location register (HLR), the visitor location register (VLR), the authentication center (AUC) and the equipment identity register (EIR). The MSC, HLR, VLR, AUC and EIR are called network station subsystem (NSS) [33,34]. The figure below shows the GSM network.

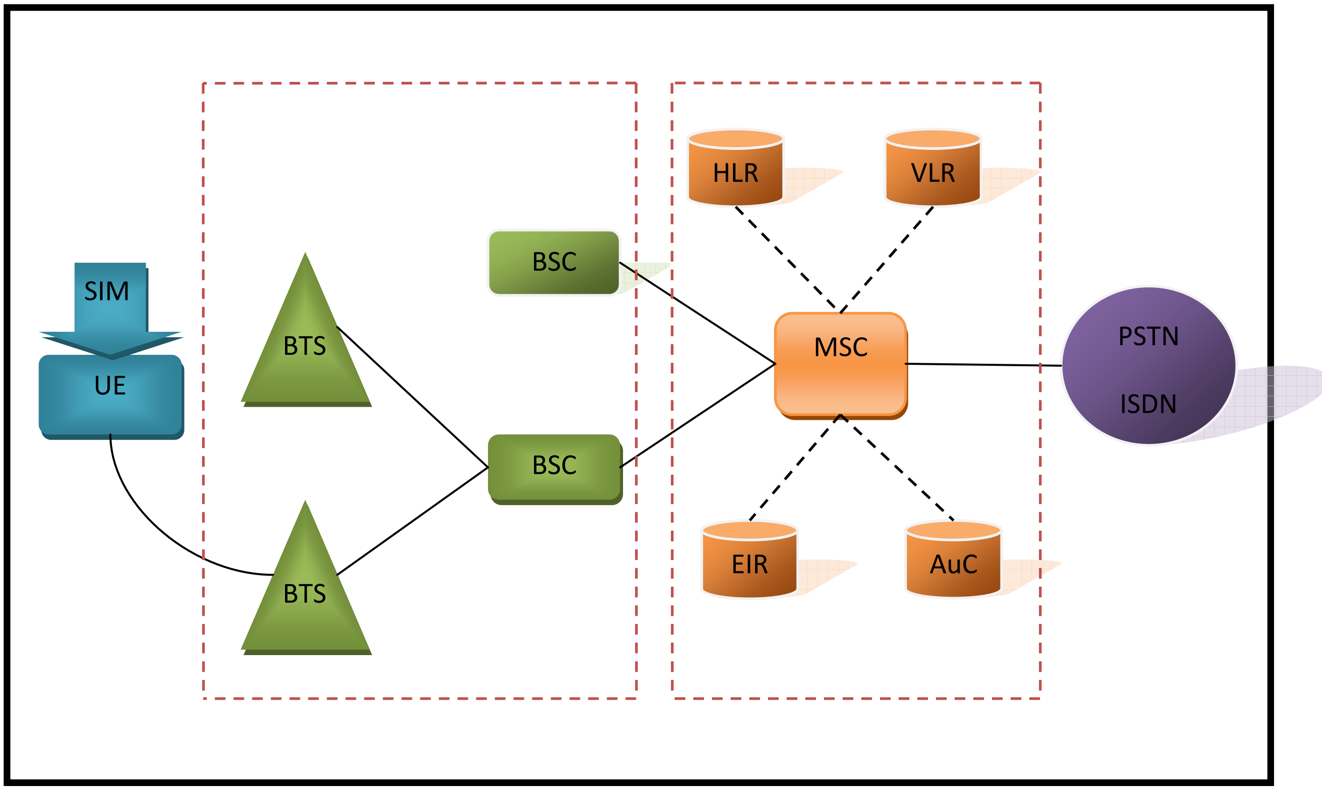


**Figure 2.2:** GSM network construction

### 2.1.3 Second and a Half Generation (2.5G)

Second and a half generation wireless service, which is the intermediate step in mobile communications, between second (2G) and third (3G) generation networks. It provides some of the benefits of 3G and can use some of the existing 2G infrastructure in GSM and CDMA networks. It extends 2G systems to provide additional features such as packet-switched connection (GPRS) and enhanced data rates (HSCSD, EDGE) [6].

#### 2.1.3.1 General Packet Radio Service (GPRS)

General Packet Radio Service is often called a 2.5G technology because it is a GSM operator's first step toward third generation (3G) and a first step in wireless data services. GPRS is a standard for wireless communications which runs at speeds up to 115 Kbps, compared with current GSM systems' 9.6 Kbps.

GPRS, which supports a wide range of bandwidths, is an efficient use of limited bandwidth and is particularly suited for sending and receiving small bursts of data, such as e-mail and Web browsing, as well as large volumes of data.

GPRS allows customers to maintain a data session while answering a phone call, which is a unique and exclusive feature to GSM. GPRS also provides an always-on data connection, so users do not have to log on each time they want data access. Like GSM, GPRS supports international roaming so customers can access data services whether they are at home or abroad. When users travel to areas that have not yet been upgraded to GPRS, they still can access many data services via circuit-switched GSM.

GPRS builds on the GSM network platform so operators can leverage their existing infrastructure, such as base stations and Mobile Switching Centers (MSCs). The GPRS core network is based on Internet Protocol (IP) standards and the existing MSCs are based upon circuit-switched technology, so they can't handle the GPRS style packet traffic. Thus two new components, called GPRS Support Nodes, are added: Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). The SGSN can be viewed as a "packet-switched MSC", it delivers packets to mobile stations (MSs) within its service area. GGSNs are used as interfaces to external IP networks such as the public Internet, other mobile service providers' GPRS services, or enterprise intranets [8,35].

### 2.1.4 Third Generation (3G)

3G refers to the third generation of mobile telephony that is cellular technology. The third generation, as the name suggests, follows two earlier generations. 3G support higher data rates, measured in kbps or Mbps, intended for applications other than voice. The shift from 2G to 3G not only gives users fresh ways to communicate but also a variety of new services such as browsing the Internet, e-mail, instant messaging, video-conferencing and digital television. 3G also makes guidance, presence, and location-based services available to mobile users. In addition, current features of mobile phones such as cameras and personal time management systems are developed. Since 2001 3G trials across the world have shown that the main development from 2G and 2,5G to 3G is faster connection speed, referring to wider bandwidth [6,9].

The standards that branded 3G are UMTS, WCDMA, TD-SCDMA, HSPA+ and CDMA2000.

#### 2.1.4.1 Universal Mobile Telecommunications System (UMTS)

UMTS, short for Universal Mobile Telecommunications System, is a 3G networking standard used throughout much of the world as an upgrade to existing GSM mobile networks. Besides voice and data, UMTS will deliver audio and video to wireless devices anywhere in the world through fixed, wireless and satellite systems.

UMTS-2100 is the most widely deployed UMTS band. UMTS network architecture comprises a radio access network referred to as UTRAN (Universal terrestrial Radio Access Network) and a core network based on the one specified for GSM. The UTRAN may implement one or two radio access technologies relaying on WCDMA access mode: UTRAN/FDD and UTRAN/TDD. The technical specifications of the UMTS network are developed by 3GPP [11,12].

#### 2.1.4.2 Wideband Code Division Multiple Access (WCDMA)

WCDMA is a 3G technology that increases data transmission rates in GSM systems by using the CDMA air interface instead of TDMA. WCDMA is based on CDMA and is the technology used in UMTS. WCDMA was adopted as a standard by the ITU under the name "IMT-2000 direct spread".

WCDMA utilizes one 5 MHz channel for both voice and data, initially offering data speeds up to 384 Kbps. There are several newer upgrades to WCDMA that offer much faster data speeds, such as HSDPA and HSPA+. These do not replace

WCDMA, but rather build on and enhance WCDMA. Therefore any phone with HSDPA or HSPA+ also includes WCDMA by definition.

WCDMA uses a core network derived from that of GSM, ensuring backward compatibility of services and allowing seamless handover between GSM access technology and WCDMA[12,36].

#### 2.1.4.3 Code Division Multiple Access 2000 (CDMA2000)

Code Division Multiple Access 2000 (CDMA2000) is the third generation solution based on CDMA IS-95 which supports 3G services as defined by ITU standards. CDMA2000 and IMT2000 define both an air interface and a core network. CDMA2000 runs in 800MHz and 1800-2000 MHz spectrum. CDMA2000 provides high quality voice and broadband data services over wireless networks.

Currently, CDMA2000 includes CDMA2000 1X and CDMA2000 EVDO standards. CDMA2000 1X (IS-2000) supports circuit-switched voice up to and beyond 35 simultaneous call per sector and high-speed data of up to 153 kbps in both directions. CDMA2000 EVDO (Evolution Data Optimized) introduces new high speed packet switched transmission techniques that are specifically designed and optimized for a data-centric broadband network that can deliver peak data rates beyond 3 Mbps in a mobile environment [13,34].

### 2.1.5 Fourth Generation (4G)

Fourth Generation is future technology for mobile and wireless communications. 4G is a step up from 3G, which is currently the most widespread, high-speed wireless service. 4G wireless is designed to solve still-remaining problems of 3G systems and to provide a wide variety of new services, from high-quality voice to high-definition video to high-data-rate wireless channels. On average, 4G wireless is supposed to be anywhere from four to ten times faster than today's 3G networks.

In 4G, carriers use orthogonal frequency division multiplexing (OFDM) instead of time division multiple access (TDMA) or code division multiple access (CDMA).

4G networks provided comprehensive and secure IP based solution, facilitating existing and emerging services. It provided to users on an "Anytime, Anywhere" basis and at much higher data rates compared to the current and previous mobile generations. 4G systems have broader bandwidth, higher data rate, and smoother and quicker handover and will focus on ensuring seamless services across a multiple of wireless systems and networks. The key is to integrate the 4G capabilities with all the existing mobile technologies through the advanced techniques of digital communications and networking. 4G systems consist of a set of various networks using IP as a common protocol such as WiMAX and LTE [12,14].

#### 2.1.5.1 Worldwide Interoperability for Microwave Access (WiMAX)

WiMAX is IEEE 802.16 standard based wireless technology for providing high speed, last mile broadband connectivity to homes and businesses and for mobile wireless networks. WiMAX offers flexible fixed and mobile wireless solutions along with high bandwidth services for extended distance coverage and a variety of applications including support of an array of multimedia functions.

The initial version of the 806.16 standard operated in 10 to 66 GHz frequency band and required line of sight towers. The IEEE 802.16 2004 standard was developed for point to point and point to multi points operations and includes profiles for operations in the 2 to 11 GHz spectrum. The other important development that took place in this period was the creation in 2001 of the industry partnership called the WiMAX forum. The WiMAX forum defines itself as an industry led nonprofit organization comprising more than 470 companies including 141 operators committed to promote and enable end to end standards based WiMAX solutions and their interoperability.

The 802.16 medium access control (MAC) is designed to support high data transfer for uplink and downlink communication between a base station and a large number of clients for continuous and bursty traffic. WiMAX also supports significant flexible operations across a wide range of spectrum allocation including both licensed and unlicensed frequencies of 2 to 11 GHz. WiMAX should be able to handle up to 70 Mbps. WiMAX system consists of two parts, the base station and the receiver and it uses OFDM technology which has a lower power consumption rate [14,15]. The figure below shows WiMax construction.

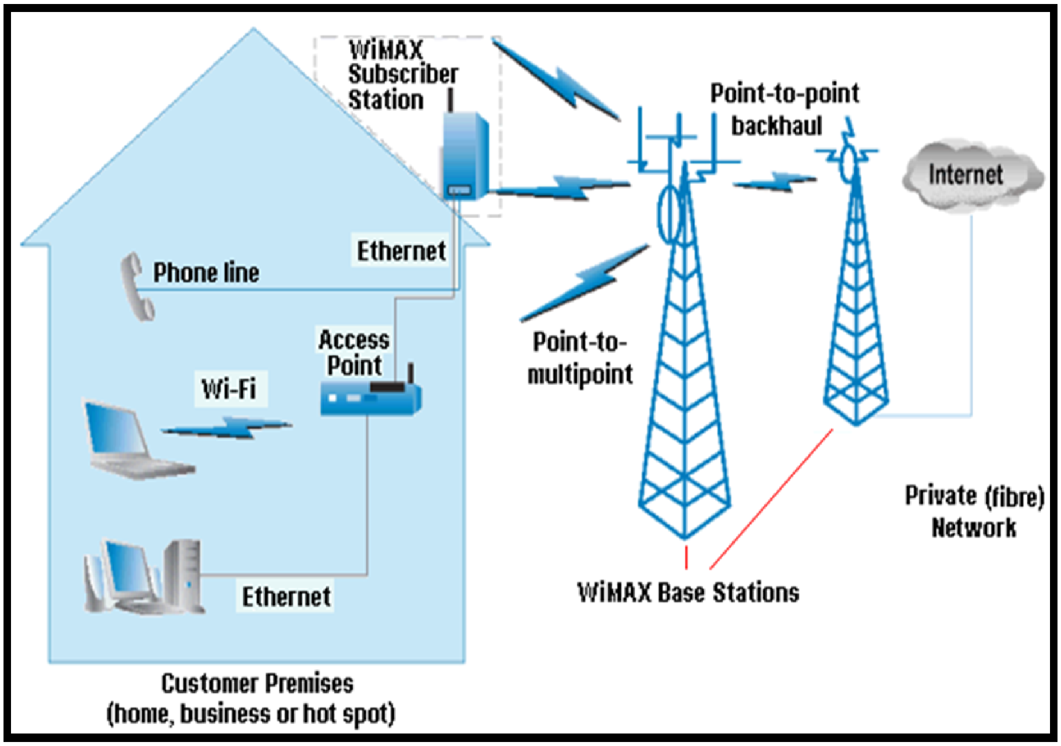


**Figure 2.3:** WiMax network construction [39]

### 2.1.5.2 Long Term Evolution (LTE)

LTE is a 4G wireless communications standard developed by the 3rd Generation Partnership Project (3GPP) that's designed to provide up to 10 times the speeds of 3G networks for mobile devices such as smart phones, tablets, notebooks and wireless hotspots. LTE technology is designed to provide IP-based voice, data and multimedia streaming at speeds of at least 100 Mbps and up to as fast as 1 Gbps.

Work on LTE began at 3GPP in 2004, with an official LTE work item started in 2006 and a completed 3GPP Release 8 specification in March 2009. Initial deployments of LTE began in late 2009.

The overall objective for LTE is to provide an extremely high performance radio access technology that offers full vehicular speed mobility and that can readily coexist with the other networks. Because of scalable bandwidth, operators will be able to easily migrate their networks and users to LTE over time.

LTE is based on OFDMA and in combination with higher order modulation (up to 64 QAM), large bandwidth (up to 20 MHz) and spatial multiplexing in the downlink (up to 4x4) high data rate can be achieved.

LTE access network is simply a network base stations, evolved node B (eNB), generating a flat architecture. There is no centralized intelligent controller, and the eNBs are normally interconnected via the X2 interface and towards the core network by the S1 interface. The reason for distributing the intelligence amongst the base station in LTE is to speed up the connection setup and reduce the time required for a handover.

LTE releases are beginning from release 8 which introduced LTE for the first time in 2008 with a completely new radio interface and core network, enabling substantially improved data performance compared with previous systems. After that release 9 in 2009 brought a number of refinements to features introduced in Release 8, along with new developments to the network architecture and new service features. Release 10 in 2011 provided a substantial uplift to the capacity and throughput of the LTE system and also took steps to improve the system performance for mobile devices located at some distance from a base station. Release 11 in 2013 will build on the platform of Release 10 with a number of refinements to existing capabilities. The last release is release 12, potential features for release 12 were discussed at a 3GPP workshop in Slovenia in June 2012. A strong requirement was the need to support the rapid increase in mobile data usage, but other items included the efficient support of diverse applications while ensuring a high quality user experience [14,38].

Figure 2.4 shows the future of the networks, where different types of technologies can work together.

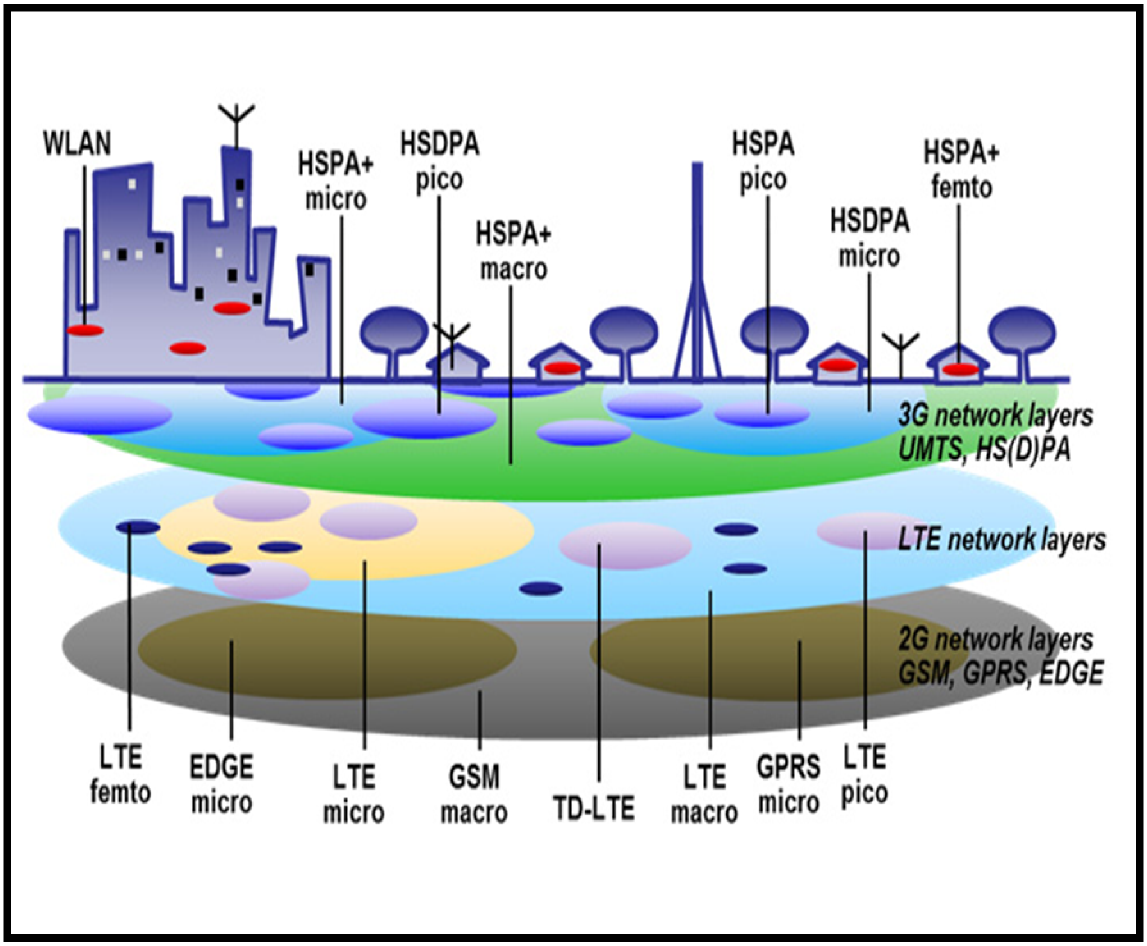


**Figure 2.4:** Heterogeneous Networks [40]

## 2.2 Classification of Network Selection Algorithms

There are various ways to classify network selection algorithms. Here, network selection algorithms are divided into four groups based on the selection decision criteria used and the methods used to process them. The table below compares the network selection criteria.

**Table 2.1:** Comparison of the Network Selection criteria

| Group | Input Parameters | Handover Target Selection Criteria | Complexity |
|---|---|---|---|
| RSS based VHD algorithms | RSS | The network candidate with the most stable RSS | simple |
| Bandwidth based VHD algorithms | Bandwidth | The network candidate with the highest bandwidth | simple |
| Cost function based VHD algorithms | Various parameters such as cost, bandwidth and security | The network candidate with the highest overall performance | complex |
| Combination algorithms | Different input parameters depending on different methods | The network candidate with the highest overall performance | Very complex |

### 2.2.1 RSS Based Algorithms

RSS is used as the main selection decision criterion in this group. Various strategies have been developed to compare the RSS of the current point of attachment with that of the candidate point of attachment. A large number of studies have been conducted in this area, here we described one of these studies.

A paper of Ahmed H. Zahran studied the performance of vertical handoff using the integration of 3G cellular and wireless local area networks (WLANs) as an example and investigated the effect of an application-based signal strength threshold on an adaptive preferred-network lifetime-based handoff strategy, in terms of the signaling load, available bandwidth, and packet delay for an inter-network roaming mobile [16].

In the first scenario, when the mobile terminal moves away from the coverage area of a WLAN into a 3G cell, a handover to the 3G network is initiated. The handover is triggered under the conditions that (a) RSS average of the WLAN connection falls below a predefined threshold, and (b) the estimated lifetime is less than or equal to the handover delay. The mobile terminal continuously calculates the RSS average using the moving average method:

$$\overline{RSS}\ [k] = \frac{1}{Wav} \sum_{i=0}^{Wav-1} \overline{RSS}\ [k-i] \qquad (2.1)$$

Here $\overline{RSS}[k]$ is the calculated average of RSS at time instant $k$, and $Wav$ is the window size of a slope estimator, a variable that changes with the velocity of the mobile terminal. Then, the lifetime metric EL$[k]$ is calculated by using $\overline{RSS}\ [k]$, the RSS change rate $S[K]$, and a parameter called Application Signal Strength Threshold (ASST) as follows:

$$\text{EL}\ [k] = \frac{\overline{RSS}[k] - ASST}{S\ [K]} \qquad (2.2)$$

The RSS change rate $S[K]$ varies with the window size of the slope estimator and the RSS sampling interval. We find the calculation of $S[K]$ in the paper. The ASST is an application dependent parameter which represents a composite of the channel bit error rate, application error resilience and application QoS requirements. A lookup table for the optimal ASST values is provided in the paper. In the second scenario, when the mobile terminal moves towards a WLAN cell, the handover to the WLAN is triggered if the average RSS measurements of the WLAN signal are larger than a threshold and the available bandwidth of the WLAN meets the bandwidth requirements of the application.

Benefits of the algorithm in this paper can be summarized as follows. First, by introducing the lifetime metric, the algorithm adapts to the application requirements and the user mobility, reducing the number of unnecessary handovers significantly. Second, there is an improvement on the average throughput for the user because of the mobile terminal's ability to remain connected to the WLAN cell as long as possible [16].

### 2.2.2 Bandwidth Based Algorithms

Available bandwidth for a mobile terminal is the main criterion in this group. In some algorithms, both bandwidth and RSS information are used in the decision process. Depending on whether RSS or bandwidth is the main criterion considered in the algorithm, in this survey, the method is classified either as RSS based or bandwidth based.

For Bandwidth based algorithms, we presented Kemeng Yang study which used received SINR from various access networks as the handoff criteria. This algorithm consider the combined effects of SINR from different access networks with SINR value from one network being converted to equivalent SINR value to the target network, so the handoff algorithm can have the knowledge of achievable bandwidths from both access networks to make handoff decisions with QoS consideration [17].

The scenario will be between WLANs and a Wideband Code Division Multiple Access (WCDMA) network using Signal to Interference and Noise Ratio (SINR). The SINR calculation of the WLAN signals is converted to an equivalent SINR to be compared with the SINR of the WCDMA channel:

$$\gamma_{AP} = \Gamma_{AP}\left[(1+\frac{\gamma_{BS}}{\Gamma_{BS}})^{\frac{W_{BS}}{W_{AP}}} - 1\right] \qquad (2.3)$$

Where $\gamma_{AP}$ and $\gamma_{BS}$ are the SINR at the mobile terminal when associated with WLAN and WCDMA, respectively. $\Gamma$ is the dB gap between the uncoded Quadrature Amplitude Modulation (QAM) and channel capacity, minus the coding gain, and $\Gamma_{AP}$ equals to 3dB for WLAN and $\Gamma_{BS}$ equals to 3dB for WLAN, as stated by the authors. $W_{AP}$ and $W_{BS}$ are the carrier bandwidths of WLAN and

WCDMA links. A handover to the network with larger SINR is performed, as shown in the flowchart below.

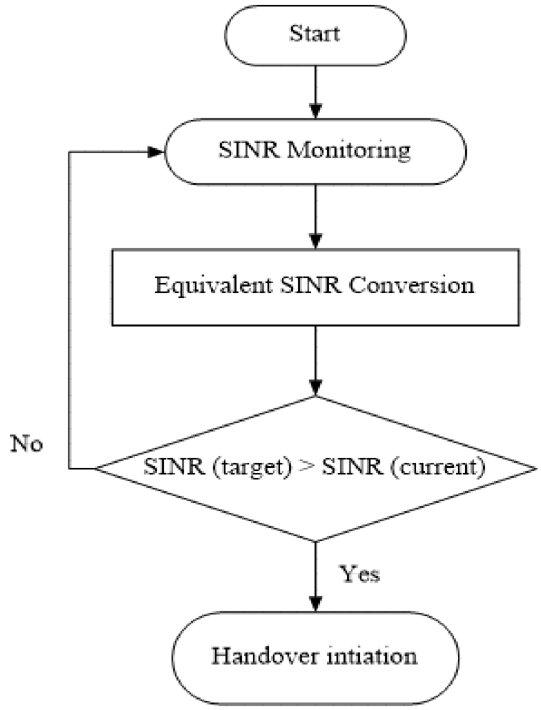


**Figure 2.5:** SINR VHD (Kemeng Yang study)

SINR based handovers can provide users with higher overall throughput than RSS based handovers since the available throughput is directly dependent on the SINR, and this algorithm results in a balanced load between the WLAN and the WCDMA networks. But such an algorithm may also introduce excessive handovers with the variation of the SINR causing the node to handover back and forth between two networks, commonly referred to as ping-pong effect [17].

### 2.2.3 Cost Function Based Algorithms

This class of algorithms combines metrics such as monetary cost, security, bandwidth and power consumption in a cost function and the selection decision is made by comparing the result of this function for the candidate networks. Different weights are assigned to different input metrics depending on the network conditions and user preferences.

Fang Zhu and Janise McNair paper introduced cost function to judge target networks based on a variety of user and network valued metrics. A network quality factor is used to evaluate the performance of a handover target candidate as:

$$Q_i = \omega_c C_i + \omega_s S_i + \omega_p P_i + \omega_d D_i + \omega_f F_i \qquad (2.4)$$

Where $Q_i$ is the quality factor of network *i*, $C_i$, $S_i$, $P_i$, $D_i$ and $F_i$ stand for cost of service, security, power consumption, network condition and network performance, and $\omega_c$, $\omega_s$, $\omega_p$, $\omega_d$ and $\omega_f$ are the weights of these network parameters. Since each network parameter has a different unit, a normalization procedure is used and the normalized quality factor for network n is calculated as:

$$Q_i = \frac{\omega_c \left(1/C_i\right)}{\max\left(\left(1/C_1\right),\ldots,\left(1/C_n\right)\right)} + \frac{\omega_s S_i}{\max(S_1,\ldots,S_n)} + \frac{\omega_p \left(1/P_i\right)}{\max\left(\left(1/P_1\right),\ldots,\left(1/P_n\right)\right)} + \frac{\omega_d D_i}{\max(D_1,\ldots,D_n)} + \frac{\omega_f F_i}{\max(F_1,\ldots,F_n)} \qquad (2.5)$$

A handover necessity estimator is also introduced to avoid unnecessary handovers [18].

### 2.2.4 Combination Algorithms

These network selection algorithms attempt to use a richer set of inputs than the others for making selection decisions. When a large number of inputs are used, it is usually very difficult or impossible to develop analytical formulations of selection decision processes.

Nidal Nasser paper discussed user’s ability to control and manage handoffs across heterogeneous wireless networks. It proposed a solution to this problem using Artificial Neural Networks (ANNs). The proposed method is capable of distinguishing the best existing wireless network that matches predefined user preferences set on a mobile device when performing a vertical handoff. The overall performance of the proposed method shows 87.0 % success rate in finding the best available wireless network.

The paper design and develop a middleware solution which we called Vertical Handoff Manager (VHM). The mobile device collects features of available wireless networks and sends them to the VHM through the existing links. These network features are used to help with handover decisions and include network usage cost, network security, network transmission range and network capacity. The vertical handover manager consists of three main components: network handling manager, feature collector and ANN training/selector. ANN is used to determine the best handover target wireless network available to the mobile device, based on the user's preferences.

The topology of the ANN consists of an input layer, a hidden layer and an output layer. The input layer consists of five nodes representing various parameters of the handover target candidate networks. The hidden layer consists of variable number of nodes which are activation functions. The output layer has one node which generates the network ID of the handover target. For ANN training they have generated a series of user preference sets with random weights. Then the system has been trained to select the best network among all the candidates. The algorithm suffers from a long delay during the training process [19].

## 2.3 Comparison of the Selection Approaches

We classified the algorithms into four groups. For comparison we summarized their features in table 1 on three aspects: input parameters, handover target selection criteria and complexity.

As for input parameters, RSS is used as the main input in RSS based VHD algorithms, while the RSS combined with the bandwidth is usually adopted in bandwidth based VHD algorithms. Various network parameters are used in cost function based or combination algorithms such as monetary cost, bandwidth, security and power consumption.

For handover target selection criteria, the candidate network with the most stable RSS and highest bandwidth is selected as the handover target in RSS and bandwidth based VHD algorithms respectively. On the other hand combination or cost function based algorithms attempt to choose the target network with the highest overall performance. The overall performance is calculated based on the various network parameters.

In terms of complexity, RSS based algorithm are usually the simplest, followed by the bandwidth based algorithm. Cost function based VHD algorithms tend to be more complex as they need to collect and normalize various network parameters and combination algorithms are the most challenging ones because of their pre training requirements.

For better understanding of the performance of different vertical handover algorithms, we provide a comparison base on the performance metrics mentioned above. Since the authors of each algorithm provide different performance parameters in their studies, direct comparisons are impossible. In table 2-2, we provide a summary quantitative comparison based on four performance parameters: delay, number of handovers, handover failure probability and throughput based on the information provided in the papers [16,17,18,19].

In summary RSS and bandwidth based VHD algorithms are usually simple, but they only consider one or two handover criteria as the inputs and other important parameters such as monetary cost or power consumption level of the networks are ignored. Cost function based and combination algorithms are more complex and they take into account wider range of network parameters as compared to others. The table blew shows the comparison of the algorithms presented in this survey.

**Table 2.2:** Comparison of the algorithms presented in this survey

| Algorithm | Group | Delay | Number of Handovers | Handover Failure Probability | Throughput |
|---|---|---|---|---|---|
| Ahmed H. Zahran | RSS based | Relatively high packet delay probability (up to 1%) but can be reduced by adjusting ASST | Reduces up to 85% comparing with traditional hysteresis VHD | Not provided | Decreases as the velocity increases; Can provide overall higher throughput (up to 33%) than traditional hysteresis VHD |
| Kemeng Yang | Bandwidth based | Not provided | Excessive handovers can be introduced because the variation of SINR | Not provided | Higher overall throughput (up to 40%) than RSS-based handover algorithms |
| Fang Zhu and Janise McNair | Cost function based | Not provided | Not provided | Not provided | High overall throughput achieved by spreading users' services over several networks |
| Nidal Nasser | Combination algorithms | Long handover delay because of the training needed | Not provided | Not provided | Not provided |

# CHAPTER THREE

# NETWORK SELECTION ALGORITHM

# Chapter Three

# Network Selection Algorithm

## 3.1 Network Selection Algorithms

Efficient network selection algorithms need to be designed to provide the required QoS to a wide range of applications while allowing seamless roaming among a multitude of access network technologies. In this chapter, a new network selection algorithm designed to satisfy these requirements is presented.

There are two processes in the network selection algorithm: network discovery and network decision. These two processes will appear in the scenario.

### 3.1.1 Network Discovery

This is the process where a mobile terminal MT searches for reachable wireless networks. A MT with multiple interfaces must activates the interfaces to receive service advertisements, which are broadcasted by different wireless technologies. The MT will know a wireless network is reachable if its service advertisements can be heard. The simplest way to discover reachable wireless networks is to always keep all interfaces on. However, keeping an interface active all the time consumes the battery power even without receiving or sending any packets. Therefore, to avoid keeping the idle interfaces always on and also the discovery time should be low so that the MT can benefit faster from the new wireless network [10][20][21].

### 3.1.2 Network Decision

Network decision is the ability to decide which access network to select. A decision for selection may depend on several issues relating to the network such as network bandwidth, load, coverage, cost, security, QoS, or even user preferences [20,21].

## 3.2 Handover

Handover is defined as a capability for managing the mobility for a mobile terminal or a moving network in active state. Handovers are a core element in planning and deploying cellular networks. It allows users to create data sessions or connect phone calls on the move. This process keeps the calls and data sessions connected even if a user moves from one cell site to another.

The important issue in handover is the need to decide when handover is necessary, and to which cell. In addition when the handover occurs it is necessary to re-route the call to the relevant base station along with changing the communication between the mobile and the base station to a new channel. All of these need to be undertaken without any noticeable interruption to the call.

There are a number of parameters that need to be known to determine whether a handover is required. The signal strength of the base station that make the communication, along with the signal strengths of the surrounding stations. Additionally the availability of channels also needs to be known.

Handover in a heterogeneous network environment is different from that in a homogeneous wireless access system where it occurs only when a user moves from one base station to another. Handover within a homogeneous system is defined as horizontal handover, but handover between different access technologies is defined as vertical handover.

In 4G, there are a large variety of heterogeneous networks. The users for variety of applications would like to utilize heterogeneous networks on the basis of their preferences such as real time, high availability and high bandwidth. When connections have to switch between heterogeneous networks for performance and high availability reasons, seamless vertical handoff is necessary. The requirements like capability of the network, network bandwidth, network cost, network conditions, power consumption and user's preferences must be taken into consideration during vertical handoff [24,25,26].

In the next section the scenario that use here for the handover above will be presented and how it simulated. The figure below shows the horizontal handover versus the vertical handover.

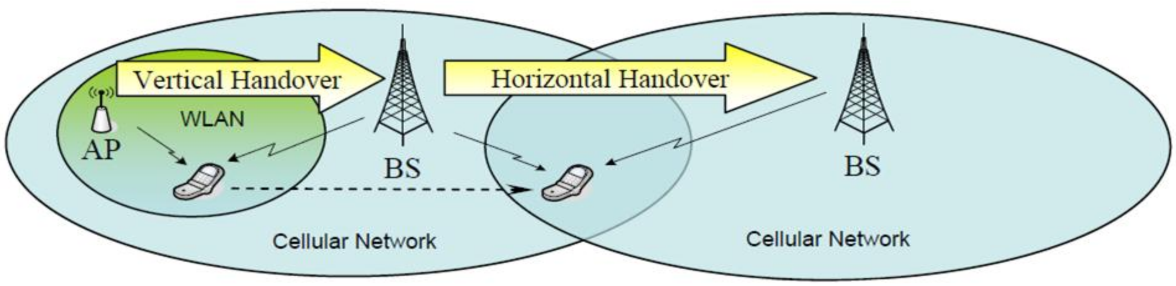


**Figure 3.1:** Vertical Handover & Horizontal Handover [26]

## 3.3 The Scenario of the Proposed Algorithm

Future wireless networks must be able to coordinate services within a diverse networks environment. One of the most challenging problems for coordination is how to select a suitable network. There are two cases for selection, when a user requests for a new service or when there is a handover request. In this thesis the handover case is simulated (vertical handoff), which is the decision for a mobile station to handoff between different types of networks. While the traditional handoff is based on received signal strength which is not sufficient to make a vertical handoff decision, as they do not take into account the various attachment options for the mobile user. So vertical handoff should evaluate additional factors, such as bandwidth availability, signal to noise ratio, offered services, network conditions, and user preferences. Therefore in this thesis a new algorithm is proposed for the execution of vertical handoff decision algorithms, with the goal of maximizing the data rate and the throughput.

The RSS based VHD algorithm is used for handoff between two networks LTE and WiMAX, by adding the bandwidth and signal to noise ratio for the algorithm to increase the throughput and data rate.

The above scenario is simulated in Matlab to show how the algorithm works better when adding additional parameters to the main selection parameter (RSS). The result figures in chapter four show the differences between the proposed algorithm and when using only RSS.

Consider that the MT moves between LTE and WiMAX. First the MT is tested, if it is in LTE or WiMAX network, if it is in the two networks at the same time, it compares the RSS for the two networks (LTE & WiMAX), then it measures the network performance for the two networks (bandwidth & SNR), the network with the best performance and higher RSS will be candidate. If the LTE network is the candidate one, the MT will stay in it or either handoff to WiMAX network. The same procedures will consider if the MT is in WiMAX network. The flow chart below shows this scenario.

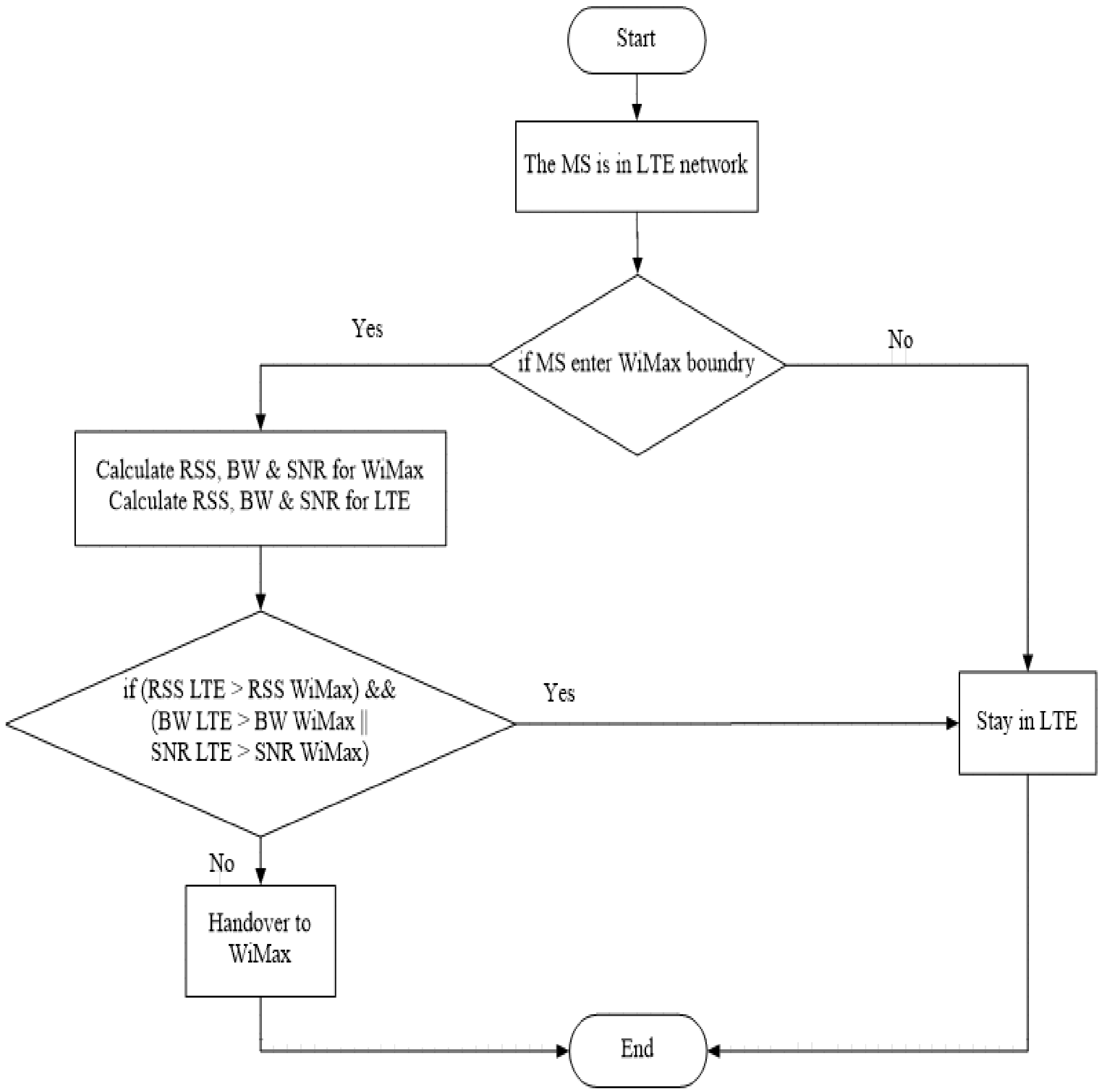


**Figure 3.2:** The proposed VHD algorithm

## 3.4 Mathematical Model

### 3.4.1 Simplified Path Loss Model

At the beginning of the scenario, we measure the RSS. The RSS fluctuates over time with the user movement, it will vary due to the path loss and shadowing and it is necessary to investigate the causes of these fluctuations.

Path loss describes the signal attenuation between the transmitter and the receiver. Shadowing is caused by obstacles between the transmitter and receiver that attenuate signal power through absorption, reflection, scattering, and diffraction. Variation due to path loss occurs over very large distances (100-1000 meters), whereas variation due to shadowing occurs over distances proportional to the length of the obstructing object (10-100 meters in outdoor environments and less in indoor environments). Since variations due to path loss and shadowing occur over relatively large distances, this variation is sometimes referred to as large-scale propagation effects [28,29].

In RSS measurements, for general tradeoff analysis of various systems designs it is sometimes best to use a simple model that captures the essence of signal propagation without resorting to complicated path loss models, which are only approximations to the real channel anyway. Thus, the following simplified model for path loss as a function of distance is commonly used for system design:

$$P_r = P_t K \left[\frac{d_0}{d}\right]^{\gamma} \qquad (3.1)$$

The dB attenuation is thus:

$$P_r \text{ dBm} = P_t \text{ dBm} + K \text{ dB} - 10\gamma \log_{10}\left[\frac{d}{d_0}\right] \qquad (3.2)$$

In this approximation, $K$ is a unit less constant which depends on the antenna characteristics and the average channel attenuation, $d_0$ is a reference distance for the antenna far-field, and $\gamma$ is the path loss exponent. The values for $K$, $d_0$ and $\gamma$ can be obtained to approximate either an analytical or empirical model. In particular, the free space path loss model, two-ray model, Hata model, and the COST extension to the Hata model are all of the same form. Due to scattering phenomena in the antenna near-field, the model is generally only valid at transmission distances $d > d_0$, where $d_0$ is typically assumed to be 1-10 m indoors and 10-100 m outdoors [28,29].

When the simplified model is used to approximate empirical measurements, the value of $K < 1$ is sometimes set to the free space path gain at distance $d_0$ assuming omnidirectional antennas:

$$K \text{ dB} = 20 \log_{10} \frac{\lambda}{4\pi d_0} \qquad (3.3)$$

And this assumption is supported by empirical data for free-space path loss at a transmission distance of 100 m. Alternatively, $K$ can be determined by measurement at $d_0$ or optimized (alone or together with γ) to minimize the mean square error (MSE) between the model and the empirical measurements. The value of γ depends on the propagation environment: for propagation that approximately follows a free-space or two-ray model γ is set to 2 or 4, respectively. The value of γ for more complex environments can be obtained via a minimum mean square error (MMSE) fit to empirical measurements. A table below summarizing γ values for different indoor and outdoor environments:

**Table 3.1:** Typical path loss exponent

| Environment | γ Range |
|---|---|
| Urban macrocells | 3.7 – 6.5 |
| Urban microcells | 2.7 – 3.5 |
| Office building (same floor) | 1.6 – 3.5 |
| Office building (multiple floors) | 2 - 6 |
| Store | 1.8 – 2.2 |
| Factory | 1.6 – 3.3 |
| Home | 3 |

Path loss exponents at higher frequencies tend to be higher while path loss exponents at higher antenna heights tend to be lower. Note that the wide range of empirical path loss exponents for indoor propagation may be due to attenuation caused by floors, objects, and partitions [28,29].

### 3.4.2 Signal to Noise Power Ratio

We define the received signal to noise power ratio (SNR) as the ratio of the received signal power $P_r$ to the power of the noise within the bandwidth of the transmitted signal $s(t)$. The received power $P_r$ is determined by the transmitted power and the path loss, shadowing, and multipath fading. The noise power is determined by the bandwidth of the transmitted signal and the spectral properties of $n(t)$. Specifically, if the bandwidth of the complex envelope $u(t)$ of $s(t)$ is $B$ then the bandwidth of the transmitted signal $s(t)$ is $2B$. Since the noise $n(t)$ has uniform power spectral density $\frac{N_0}{2}$, the total noise power within the bandwidth $2B$ is:

$$N = \frac{N_0}{2} * 2B = N_0 B \qquad (3.4)$$

So the received SNR is given by

$$\text{SNR} = \frac{P_r}{N_0 B} \qquad (3.5)$$

In systems with interference, we often use the received signal to interference plus-noise power ratio (SINR) in place of SNR for calculating error probability. If the interference statistics approximate those of Gaussian noise then this is a reasonable approximation. The received SINR is given by

$$\text{SINR} = \frac{P_r}{N_0 B + PI} \qquad (3.6)$$

Where $PI$ is the average power of the interference. The SNR is often expressed in terms of the signal energy per bit $E_b$ or per symbol $E_s$ as

$$\text{SNR} = \frac{P_r}{N_0 B} = \frac{E_s}{N_0 B T_s} = \frac{E_b}{N_0 B T_b} \qquad (3.7)$$

Where $T_s$ is the symbol time and $T_b$ is the bit time (for binary modulation $T_s$= $T_b$ and $E_s$= $E_b$) [28].

According to the calculated SNR the modulation type can be chosen. From the modulation type we use the modulation index to calculate the data rate and the throughput as shown in the paragraphs below.

### 3.4.3 Data Rate

Data rate is one of the basic characteristics of communication systems and is the rate at which bits is transmitted over a channel in bit/sec or bps [30]. We can derive the data rate by multiplying mutual information with the bandwidth of the channel as shown below:

$$\text{Data rate} = \text{MI} \times \text{BW} \qquad (3.8)$$

MI has the meaning of the number of effective bits that can be transported at a certain SNR level. It is always below the Shannon bound:

$$\text{MIShannon (SNR)} = \log_2\left(1 + 10^{\frac{SNR}{10dB}}\right) \qquad (3.9)$$

In reality, each modulation grade comes with its own MI level, depending on SNR. In low SNR regions, MI is limited by the Shannon bound. In high SNR regions it is saturated and limited by the number of bits the modulation scheme supports (m). The region in between is influenced by both effects and handled by this new formula:

$$\text{MI (SNR, m)}= \frac{1}{(S.MIShannon\,[DNR]^{-w} + m^{-w})^{1/w}} \qquad (3.10)$$

Using the following abbreviations

$$s = s\ (m) = 0.95 – 0.08.\ (m \bmod 2) \qquad (3.11)$$

$$w=w\ (m) =2.m+1 \qquad (3.12)$$

Where m is the modulation index, i.e. the number of bits per symbol (1=QPSK...8=QAM256). The scale factor s (m) reveals the remarkable fact that square-shaped modulation constellations (m=2, 4, 6, 8) perform slightly better than the other I/Q asymmetric constellations. The MI value has the unit of [Mbit/s/Hz] [41].

### 3.4.4 Throughput:

The throughput is usually measured in bits per second (bit/s or bps), and sometimes in data packets per second or data packets per slot. The system throughput or aggregate throughput is the sum of the data rates that are delivered to all terminals in a network. Throughput is essentially synonymous to digital bandwidth consumption, it can be analyzed mathematically by means of queuing theory, where the load in packets per time unit is denoted arrival rate $\lambda$, and the throughput in packets per time unit is denoted departure rate $\mu$ [28,30].

$$\text{Throughput} = \text{sum (data rate)} \qquad (3.13)$$

# CHAPTER FOUR

# RESULTS AND DISCUSSION

# Chapter Four

# Results and Discussion

In this section, the results are obtained from the mathematical expressions presented in the previous section in chapter three based on Matlab simulation. The Matlab code can be found in the appendix. These results are obtained for different modulation schemes i.e. QPSK, 16-QAM and 64-QAM.

## 4.1 Environment and Parameters Assumptions

Table 4.1 gives a list of main simulation parameters used through the simulation performances. These parameters are widely used to simulate the wireless cellular networks.

**Table 4.1:** simulation parameters

| Parameters | Values |
|---|---|
| LTE frequency | 2.3 GHz |
| WiMax frequency | 2.5 GHz |
| LTE transmit power | 33 dBm |
| WiMax transmit power | 26 dBm |
| LTE bandwidth range | 3.5 – 20 MHz |
| WiMax bandwidth range | 1.25 – 10 MHz |
| Mobile station speed | 10 m/s |
| LTE point | 0 |
| WiMax point | 600 |
| Mobile station point | 100 |

## 4.2 Simulation Results and Discussion:

In this phase, the system performance has been compared between the two algorithms, when using only RSS and when adding the bandwidth and SNR to the selection criteria.

At the beginning, the MS will be in the LTE network and moving toward WiMax which is a microcell inside LTE network. When the MS is in LTE network, it will be in it until it arrives the boundary of WiMax, firstly in the algorithm which is depending on RSS only, the mobile compares the RSS for the LTE and WiMax networks and selects the network with the highest RSS but in the algorithm where additional parameters added to the RSS (bandwidth and SNR), it will give higher data rate and throughput as shown in the results.

All of the results in this phase are demonstrated against time because most of the wireless channel parameters have random values which are changed with time so if one value is chosen it will not give the right evaluation of the system that's why different values at different time are taken to measure the performance of the system.

Figure 4.1 illustrates the different RSS values for the LTE and WiMax networks with the time. In the figure the LTE RSS decreases with time as the MS moves away from the antenna and the WiMax RSS decreases in the boundary of the cell and increases when the MS is closer to the antenna of WiMax BS.

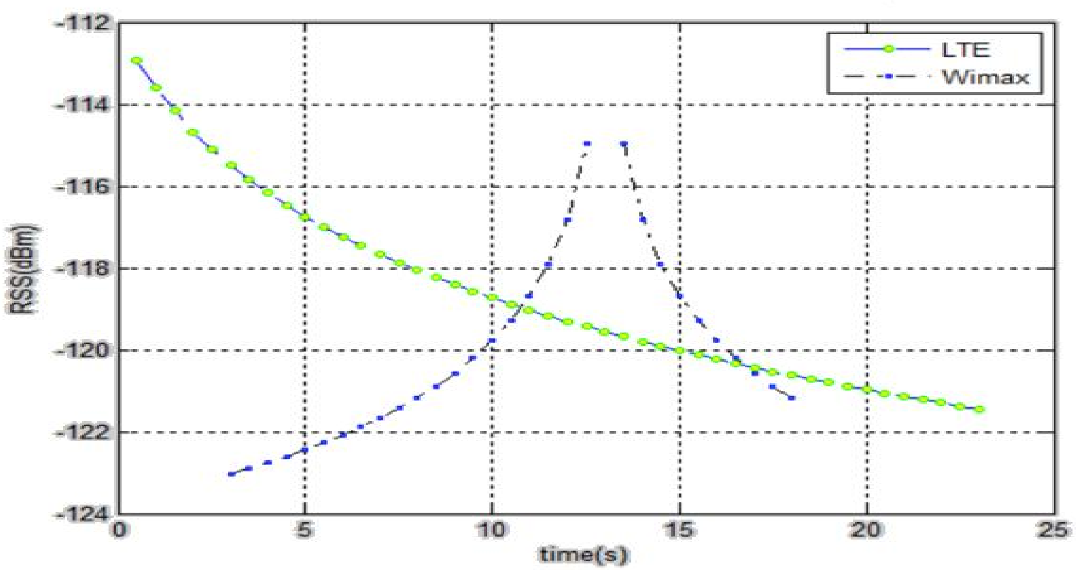


**Figure 4.1:** The received signal strength for the LTE and WiMax networks

Figure 4.2 illustrates the SNR for LTE and WiMax networks which is changing with time.

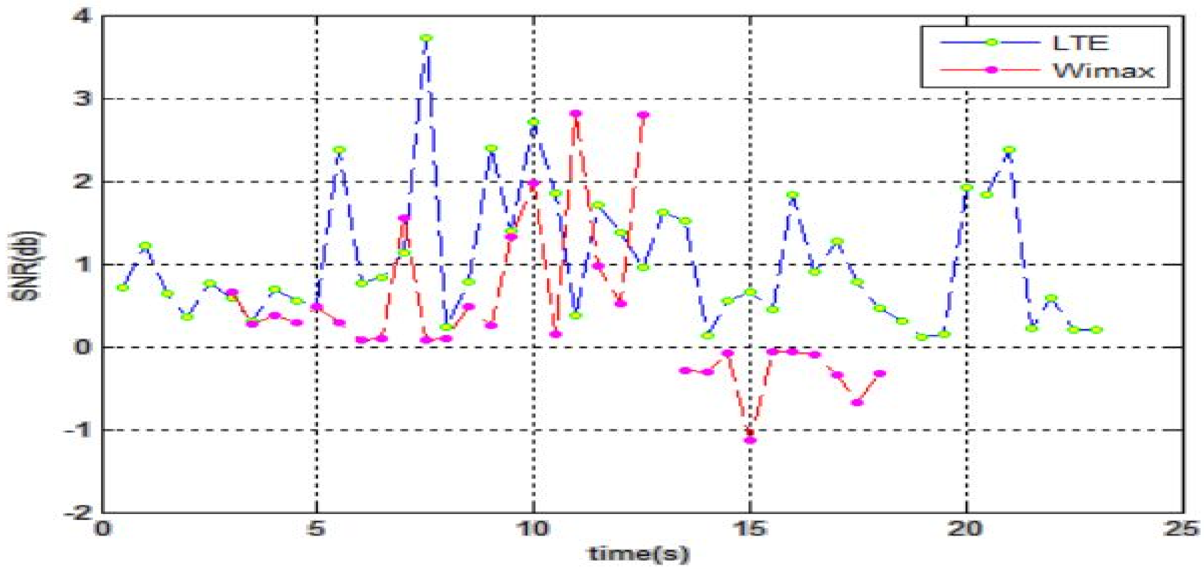


**Figure 4.2:** The SNR for the LTE and WiMax networks

Figure 4.3 illustrates the bandwidth for LTE and WiMax networks which is changing with time.

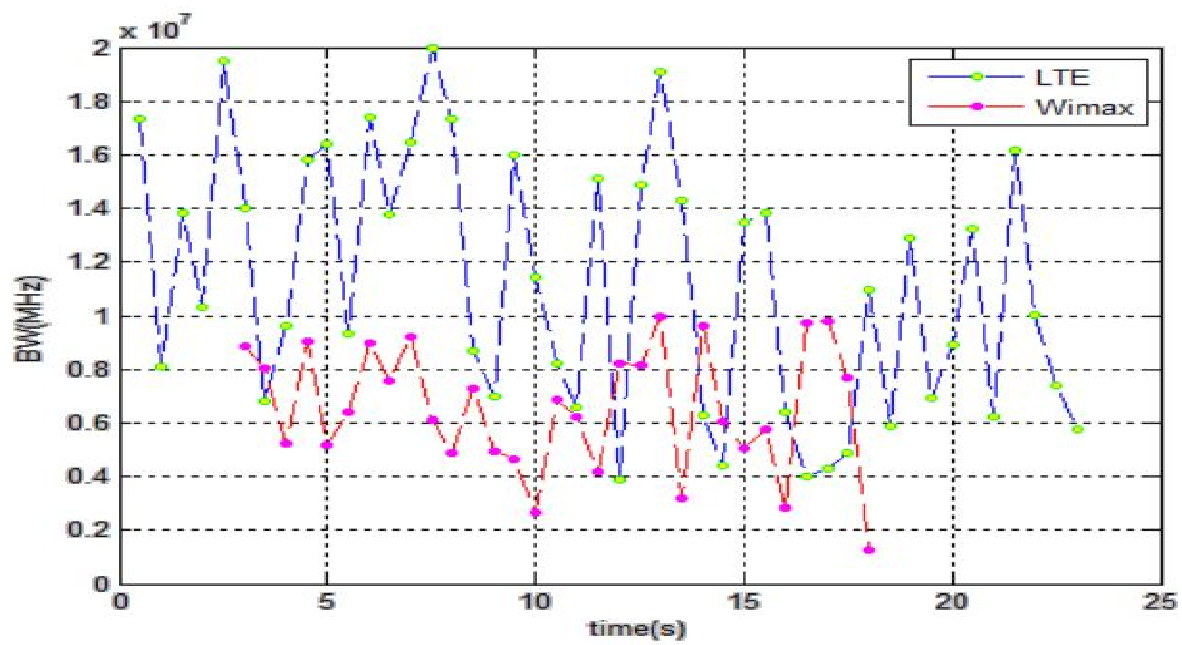


**Figure 4.3:** The bandwidth for the LTE and WiMax networks

Figure 4.4 illustrates the data rate for LTE and WiMax networks which is changing with time.

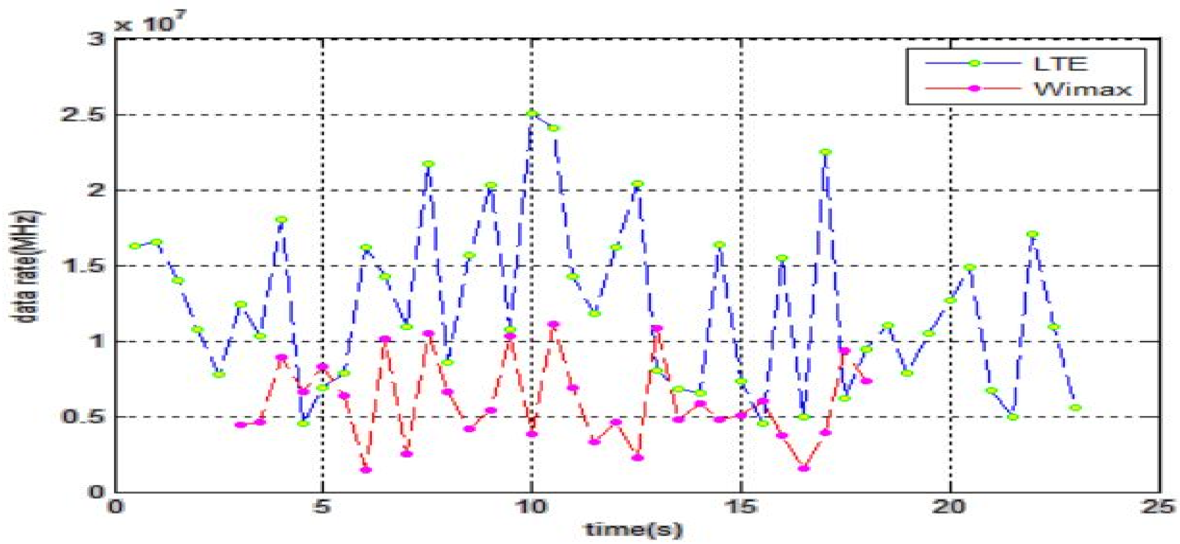


**Figure 4.4:** The data rate for the LTE and WiMax networks

Figure 4.5 illustrates the throughput for LTE and WiMax networks which is changing with time.

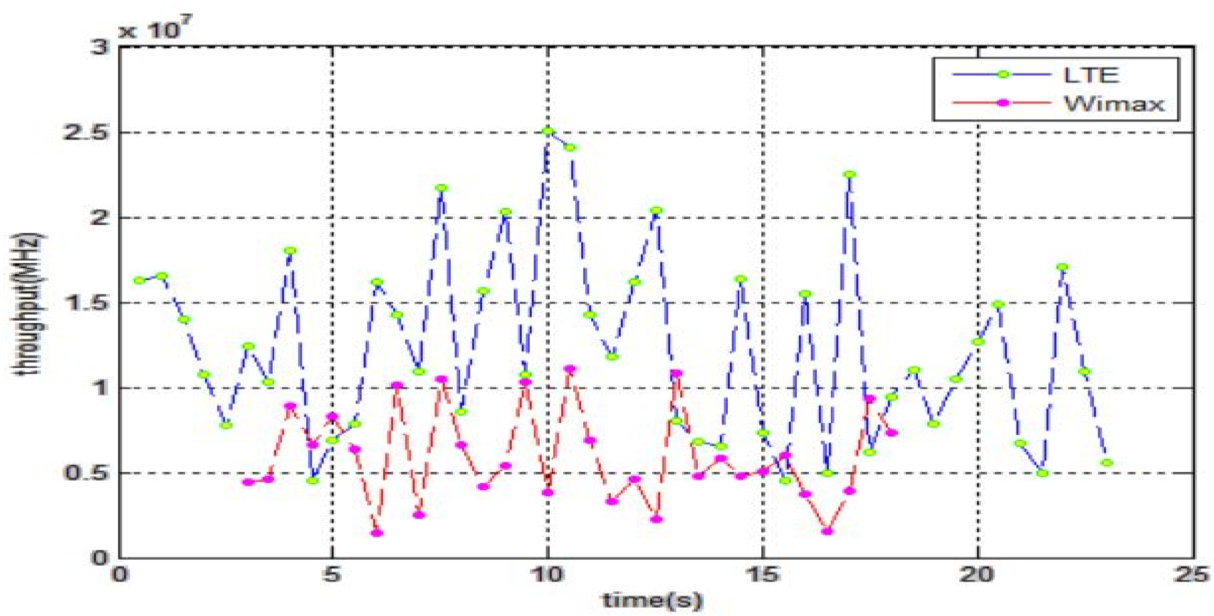


**Figure 4.5:** The throughput for the LTE and WiMax networks

Figure 4.6 illustrates the handover depending on the RSS only. As the figure the MS stays in the LTE network although it is in WiMax network, it handoffs only when the RSS for WiMax became higher than RSS for LTE.

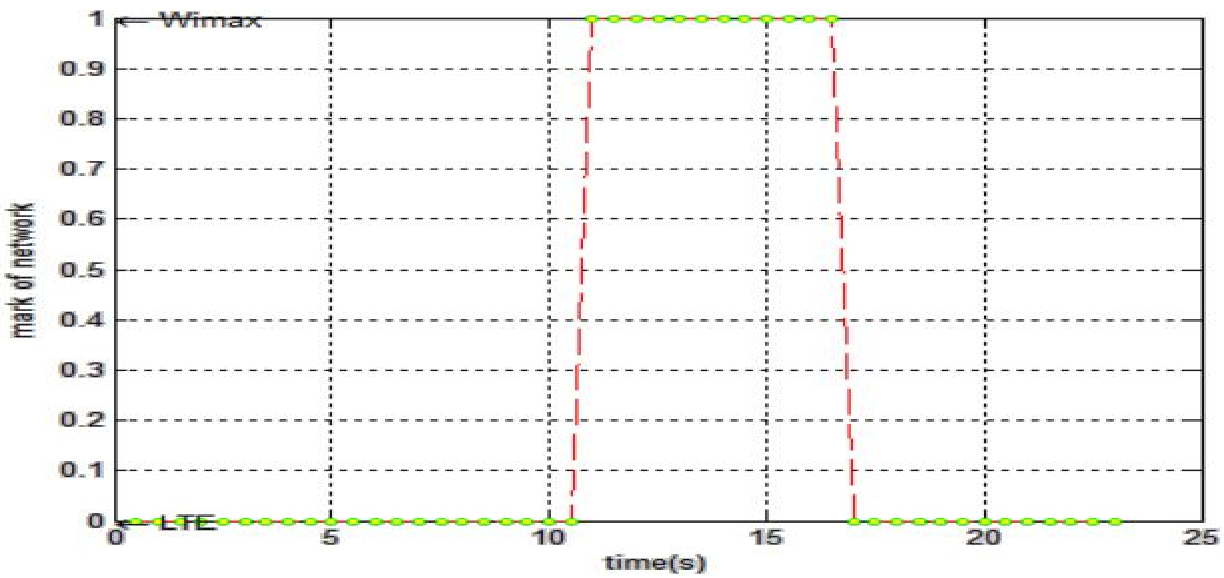


**Figure 4.6:** The state of the MS in the LTE and WiMax networks (RSS only)

In figure 4.7, although the RSS of the WiMax is higher, the handover does not occur because of the bandwidth and SNR. The handover occurs according to these two additional parameters.

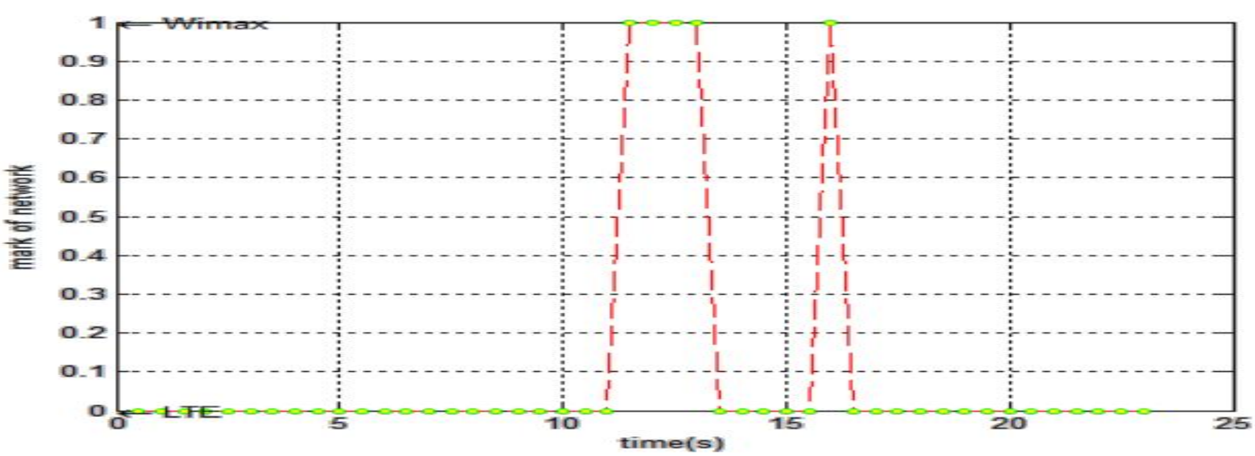


**Figure 4.7:** The state of the MS in LTE and WiMax networks (the proposed algorithm)

Figure 4.8 shows the differences in handover when only RSS using and when SNR and bandwidth are adding to the selection criteria.

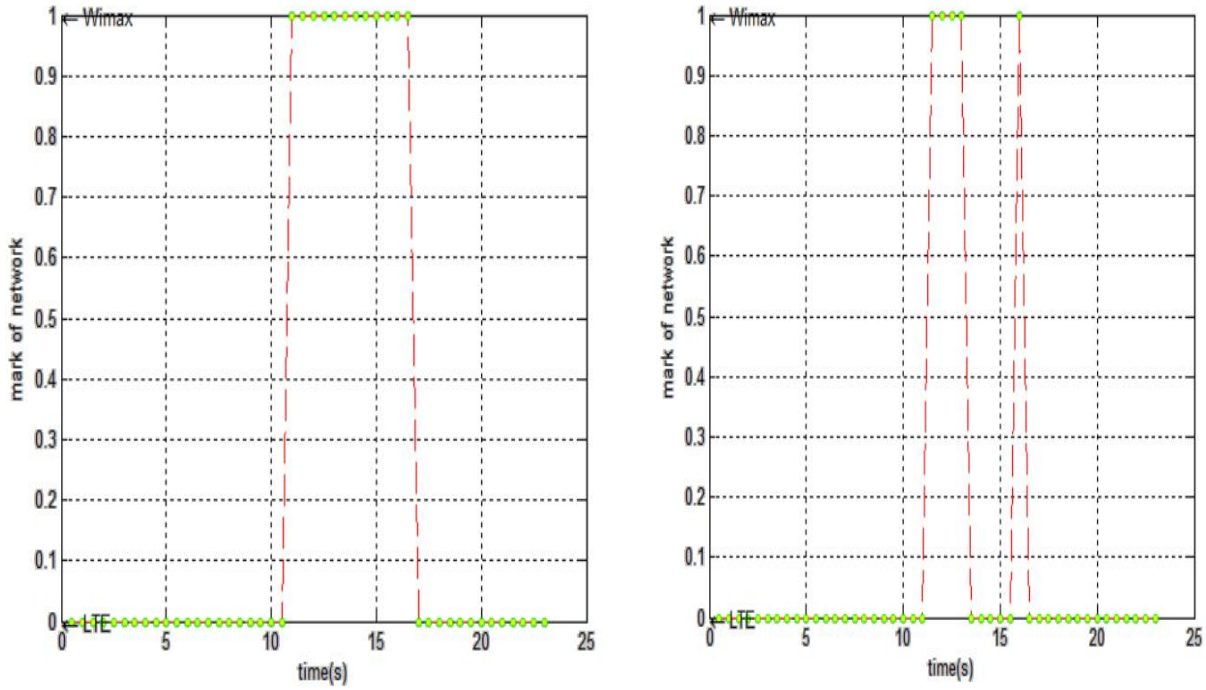


**Figure 4.8:** The differences in the handover

In the figure 4.9, the picture in the right shows that the data rate in the time between 11 - 17 s is higher than the data rate in the left picture in the same time. This time where the handover occurs in the two cases. So adding additional parameters to the RSS gains data rate higher with 160% than using only RSS.

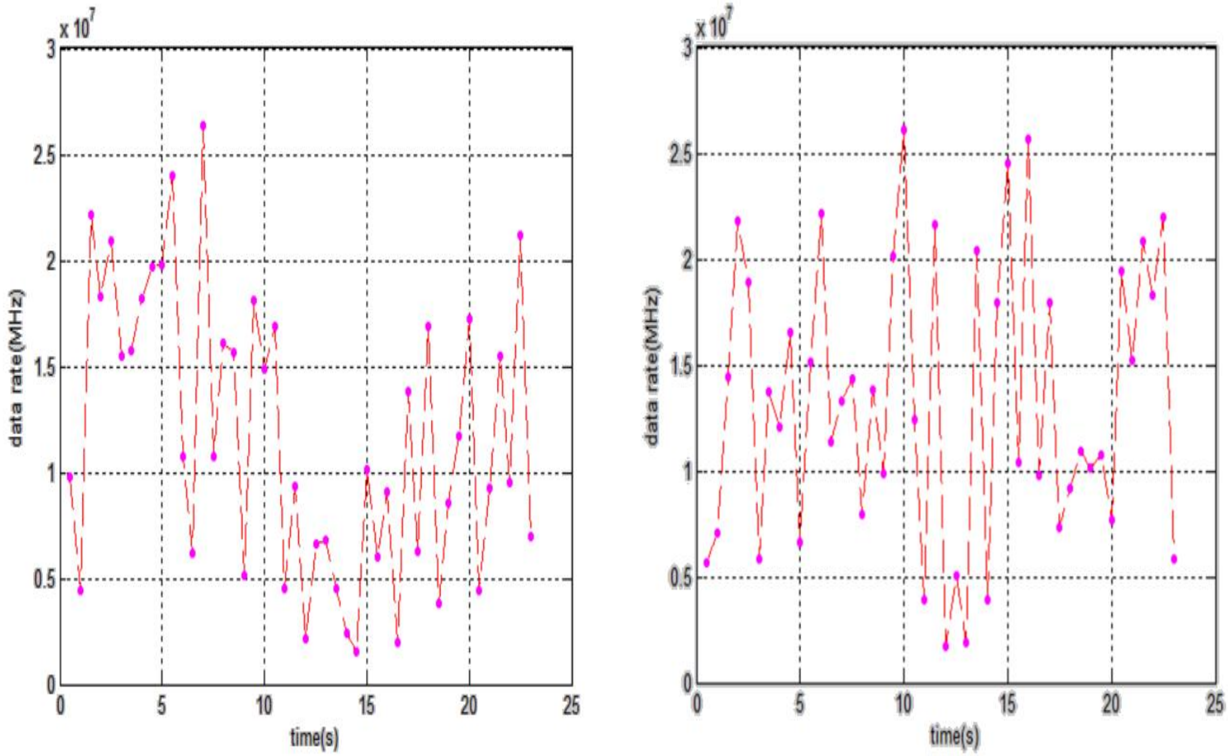


**Figure 4.9:** The differences in the data rate

In the figure 4.10 also in the time between 11 – 17 s where the handover occurs in the two cases, the throughput is higher by using more parameters than using only RSS.

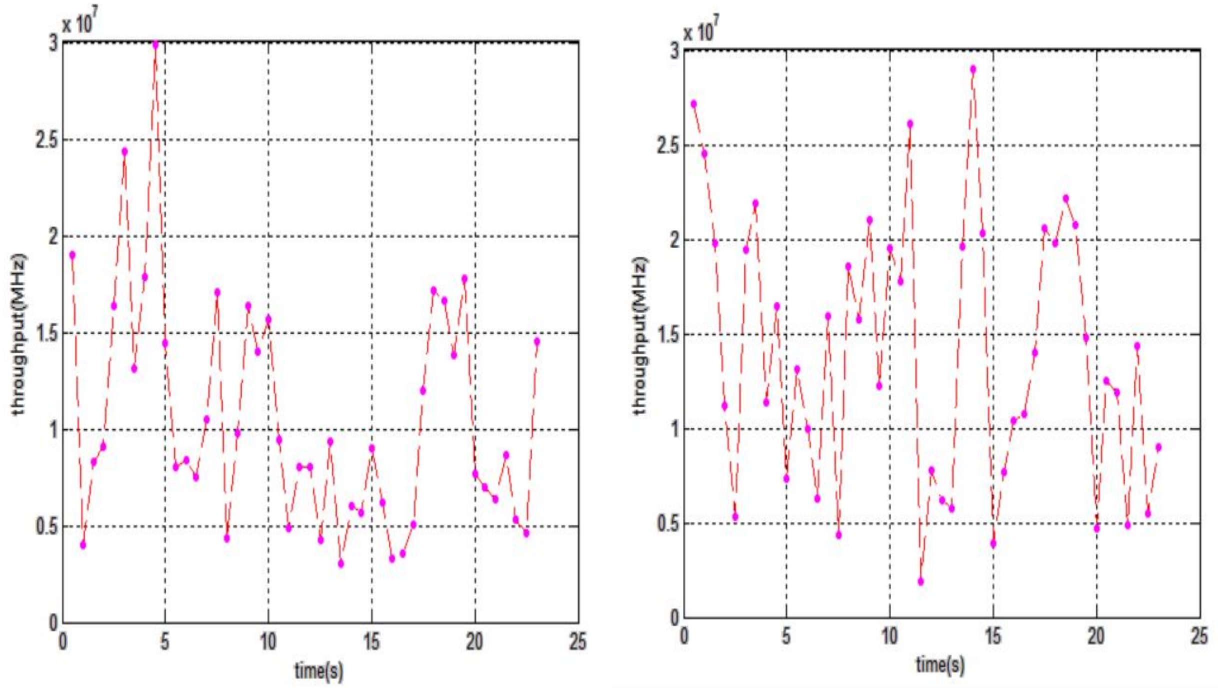


**Figure 4.10:** The differences in the throughput

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

# Chapter Five

# Conclusion and Recommendations

## 5.1 Conclusion

Seamless vertical handover between different access networks in the 4G heterogeneous wireless networks remains a challenging problem. In order to provide QoS inside the integrated network environment, the vertical handover algorithm needs to be QoS aware, which cannot be achieved by RSS based handover criteria. The new vertical handover algorithm has been proposed in this thesis using bandwidth and SNR with RSS from WiMax and LTE networks as the handover criteria.

Here we considered two 4G networks (LTE and WiMax) and perform a handover between them using Matlab. We compare between two types of algorithms for handover, the first one depends on RSS only and the second one depends on additional parameters with RSS (bandwidth and SNR). The MS will be in LTE moving toward WiMax. When it arrives the boundary of WiMax, the algorithms are worked because the MS detects two networks and it will try to select one of them according to the parameters.

Analysis results show that the performance of the second handover algorithm is able to consistently offer the end user with maximum available throughput during vertical handover. Simulation results also confirm that the new algorithm provides higher overall system throughput and data rate comparing with the RSS based vertical handover algorithm.

## 5.2 Recommendations

The vertical handover is a very important capability in the future wireless communication era, where an integrated network grouping multiple technologies will try to offer global broadband access to mobile users.

Future work might improve in the algorithm used here by adding additional parameters for network selection in HetNet to obtain great results. Also consider the type of services in selection, if the service is real time or non real time. Finally using effective criteria to handle ping pong effect and minimize superfluous handovers.

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# Appendix A

```
   clear all ,clc,close all,clf

MS_coordinate=100;          %the coordinate of MS
LTE_BS_coordinate=0;        %the coordinate of LTE BS
Wimax_BS_coordinate=600;    %the coordinate of wimax BS
MS_speed=40;       %the speed of mobile station (m/s)
fc_LTE=2300*10^6;  %the frequency of the carrier for LTE (Hz)
fc_Wimax=2500*10^6; %the frequency of the carrier for Wimax (Hz)
Net_state=0;          %0 refers to LTE;1 refers to Wimax
count_handoff_number=0;
Tc=0.5;                              %time of measure interval (s)
record_time=0; %record the number of interval time of system
countinue_run=true;
d0=10;  %Reference distance for the antenna far field minimum
%value is choosen in m
y1=3.7;                              %Path loss exponent according to
urban macrocell
y2=2.7;                              %Path loss exponent according to
urban microcell
pt_LTE=33;                           %Transmit powr for LTE (dbm)
pt_Wimax=26;                         %Transmit powr for Wimax (dbm)
c=3*10^8;                                         %Speed of light
lammda1=c/fc_LTE;                    %Wavelength for LTE (m)
k1=20*log(lammda1/(4*pi*d0)); %Constant Depend on antenna
%characteristics (db)
lammda2=c/fc_Wimax;        %Wavelength for Wimax (m)
k2=20*log(lammda2/(4*pi*d0));        %Constant Depend on antenna
%characteristics (db)
a1=3.5*10^6; b1=20*10^6;  % The range of available bandwidth for
%LTE (Hz)
a2=1.25*10^6; b2=10*10^6; % The range of available bandwidth for
%Wimax (Hz)
c1=-110; E1=-125;
c2=-110; E2=-125;

while countinue_run

%decide whether the mobile station is in the LTE network
if MS_coordinate<=1000&MS_coordinate>=100
   d1=MS_coordinate-LTE_BS_coordinate;   %Distance from LTE Bs
%to UE (m)
   RSS_LTE=pt_LTE+k1-y1*log(d1/d0);  %Received power from LTE
%cell due to path loss (dbm)
   BW_LTE=(a1+(b1-a1).*rand);
   n_LTE=(c1+(E1-c1).*rand);      % Noise Range For LTE(dbm)
```

```
   SNR_LTE_db=RSS_LTE-n_LTE;
   SNR_LTE=10.^( SNR_LTE_db/10);    % SNR for LTE
   if (SNR_LTE>=-5.1&&SNR_LTE<7.9)
           m=2;
   elseif (SNR_LTE>=7.9&&SNR_LTE<15.3)
           m=4;
    else
           m=6;
   end
     w= 2 * m + 1;
     s= 0.95 - 0.08 * mod(m,2);                % The scale factor
     MIshannon= log2(1 + 10^(SNR_LTE/10));
     MI=1/((s *MIshannon)^-w + m^-w)^(1/w);
     data_rate_LTE=BW_LTE*MI;    % Data rate for LTE
     tp_LTE=sum(data_rate_LTE);  % Throughput for LTE
     ef_LTE=data_rate_LTE/BW_LTE;  % Spetral efficiency for LTE
 else
   RSS_LTE=-inf;
   BW_LTE=-inf;
   n_LTE=-inf;
   SNR_LTE_db=-inf;
   SNR_LTE=-inf;
   w=-inf;
   s=-inf;
   MIshannon=-inf;
   MI=-inf;
   data_rate_LTE=-inf;
   tp_LTE=-inf;
   ef_LTE=-inf;
end

%decide whether the mobile station is in the Wimax network
if MS_coordinate<=800&MS_coordinate>=200
   d2=Wimax_BS_coordinate-MS_coordinate;    %Distance from Wimax
%Bs to UE (m)
   RSS_Wimax=pt_Wimax+k2-y2*log(d2/d0);    %Received power from
%Wimax cell due to path loss (dbm)
   BW_Wimax=(a2+(b2-a2).*rand);
   n_Wimax=(c2+(E2-c2).*rand);  % Noise Range For Wimax(dbm)
   SNR_Wimax_db=RSS_Wimax-n_Wimax;
   SNR_Wimax=10.^(SNR_Wimax_db/10);    % SNR for Wimax
   if (SNR_Wimax>=-5.1&&SNR_Wimax<7.9)
           m1=2;
   elseif (SNR_Wimax>=7.9&&SNR_Wimax<15.3)
           m1=4;
    else
           m1=6;
```

```
   end
     w1= 2 * m1 + 1;
     s1= 0.95 - 0.08 * mod(m1,2); % The scale factor
     MIshannon1= log2(1 + 10^(SNR_Wimax/10));
     MI1=1/((s1 *MIshannon)^-w1 + m1^-w1)^(1/w1);
     data_rate_Wimax=BW_Wimax*MI1;
     tp_Wimax=sum(data_rate_Wimax);
     ef_Wimax=data_rate_Wimax/BW_Wimax;
 else
   RSS_Wimax=-inf;
   BW_Wimax=-inf;
   n_Wimax=-inf;
   SNR_Wimax_db=-inf;
   SNR_Wimax=-inf;
   w1=-inf;
   s1=-inf;
   MIshannon1=-inf;
   MI1=-inf;
   data_rate_Wimax=-inf;
   tp_Wimax=-inf;
   ef_Wimax=-inf;
end

%decide whether to handoff
if (MS_coordinate<=1000&MS_coordinate>=100)&&(RSS_LTE<RSS_Wimax)
    if BW_LTE<BW_Wimax||SNR_LTE<SNR_Wimax     %compare the
%performance of new network with the past one
      Net_state=1;
      data_rate_MS=data_rate_Wimax;
      tp_MS=tp_Wimax;
      ef_MS=ef_Wimax;
   count_handoff_number=count_handoff_number+1;
else
   Net_state=0;            %stay in the past network
   data_rate_MS=data_rate_LTE;
   tp_MS=tp_LTE;
   ef_MS=ef_LTE;
    end
elseif
(MS_coordinate<=1000&MS_coordinate>=100)&&(RSS_LTE>RSS_Wimax)
   if BW_LTE>BW_Wimax||SNR_LTE>SNR_Wimax       %compare the
%performance of new network with the past one
     Net_state=0;
     data_rate_MS=data_rate_LTE;
     tp_MS=tp_LTE;
     ef_MS=ef_LTE;
   count_handoff_number=count_handoff_number+1;
```

```
else
    Net_state=1;            %stay in the past network
    data_rate_MS=data_rate_Wimax;
    tp_MS=tp_Wimax;
    ef_MS=ef_Wimax;
end
end

%decide whether to continue run
if MS_coordinate<=1000&MS_coordinate>=100

%record the data
record_time=record_time+1;
record_RSS_LTE(record_time)=RSS_LTE;
record_RSS_Wimax(record_time)=RSS_Wimax;
record_Net_state(record_time)=Net_state;
record_SNR_LTE(record_time)=SNR_LTE;
record_SNR_Wimax(record_time)=SNR_Wimax;
record_BW_LTE(record_time)=BW_LTE;
record_BW_Wimax(record_time)=BW_Wimax;
record_data_rate_LTE(record_time)=data_rate_LTE;
record_data_rate_Wimax(record_time)=data_rate_Wimax;
record_tp_LTE(record_time)=tp_LTE;
record_tp_Wimax(record_time)=tp_Wimax;
record_data_rate_MS(record_time)=data_rate_MS;
record_tp_MS(record_time)=tp_MS;
MS_coordinate=MS_coordinate+(MS_speed*Tc);
else
countinue_run=false;
end
end

%plot the simulation results
t=(1:record_time)*Tc;
plot(t,record_RSS_LTE,'b--
O','MarkerEdgeColor','g','MarkerFaceColor','y',...
    'MarkerSize',2);
hold on
plot(t,record_RSS_Wimax,'-.ks','MarkerEdgeColor','b',...
    'MarkerFaceColor','c','MarkerSize',2);
hold off
grid on
xlabel('time(s)');
ylabel('RSS(dBm)');
legend('LTE','Wimax');
title('The received signal strength for the two networks');
figure
```

```
plot(t,record_Net_state,'--
ro','MarkerEdgeColor','g','MarkerFaceColor','y',...
    'MarkerSize',2)
grid on
xlabel('time(s)');
ylabel('mark of network');
text(0,0,'\leftarrow LTE','FontSize',10)
text(0,1,'\leftarrow Wimax','FontSize',10)
title('The state of mobile station in LTE and Wimax network')
figure
plot(t,record_SNR_LTE,'b--
O','MarkerEdgeColor','g','MarkerFaceColor','y',...
    'MarkerSize',2);
hold on
plot(t,record_SNR_Wimax,'r--O','MarkerEdgeColor','m',...
    'MarkerFaceColor','m','MarkerSize',2);
hold off
grid on
xlabel('time(s)');
ylabel('SNR(db)');
legend('LTE','Wimax');
title('The signal to noise ratio for the two networks');
figure
plot(t,record_BW_LTE,'b--
O','MarkerEdgeColor','g','MarkerFaceColor','y',...
    'MarkerSize',2);
hold on
plot(t,record_BW_Wimax,'r--O','MarkerEdgeColor','m',...
    'MarkerFaceColor','m','MarkerSize',2);
hold off
grid on
xlabel('time(s)');
ylabel('BW(MHz)');
legend('LTE','Wimax');
title('The bandwidh for the two networks');
figure
plot(t,record_data_rate_LTE,'b--
O','MarkerEdgeColor','g','MarkerFaceColor','y',...
    'MarkerSize',2);
hold on
plot(t,record_data_rate_Wimax,'r--O','MarkerEdgeColor','m',...
    'MarkerFaceColor','m','MarkerSize',2);
hold off
grid on
xlabel('time(s)');
ylabel('data rate(MHz)');
legend('LTE','Wimax');
```

```
title('The data rate for the two networks');
figure
plot(t,record_tp_LTE,'b--
O','MarkerEdgeColor','g','MarkerFaceColor','y',...
    'MarkerSize',2);
hold on
plot(t,record_tp_Wimax,'r--O','MarkerEdgeColor','m',...
    'MarkerFaceColor','m','MarkerSize',2);
hold off
grid on
xlabel('time(s)');
ylabel('throughput(MHz)');
legend('LTE','Wimax');
title('The throughput for the two networks');
figure
plot(t,record_data_rate_MS,'r--O','MarkerEdgeColor','m',...
    'MarkerFaceColor','m','MarkerSize',2);
grid on
xlabel('time(s)');
ylabel('data rate(MHz)');
title('The data rate for the mobile station');
figure
plot(t,record_tp_MS,'r--O','MarkerEdgeColor','m',...
    'MarkerFaceColor','m','MarkerSize',2);
grid on
xlabel('time(s)');
ylabel('throughput(MHz)');
title('The throughput for the mobile station');

%###################END THE PROGRAM###################
```