CHAPTER 1

1.1 BACKGROUND

There is a widespread growth and organization of various wireless networks to meet the demands of user. The growing prospect of global connectivity has made the developments in technology to be furthermore transformative in the past period [1]. Future Telecommunication networks target at providing cohesive services such as voice, data and multimedia via reasonably priced low powered mobile computing device over wireless infrastructure. Amalgamation of heterogeneous wireless networks is anticipated to gain impetus in the development of wireless networks of the next generation [2]. Through coexistence or by congregated system and by using common infrastructure to communicate with the multiple access networks; one can provide both widespread coverage and access to broadband [3, 4].

In the heterogeneous wireless network (HWN) of next generation an IP can be used as a de-facto protocol for inter operation amongst diverse communication protocols. In addition a protocol stack has to be developed that will adapt itself to the different network features [2]. Finally, users may flawlessly switch between different accessible technologies by using an intelligent and adaptive terminal device, and access points (AP’s) with multiple air interfaces.

1.2 OVERVIEW OF WIRELESS AND MOBILE NETWORKS

Wireless network provides mobility for the users as per convenience. Different heterogeneous wireless technologies are available to meet the need of users and to support diverse applications.

1.2.1 Wireless Technology Evolution Path

There is a varied choice of accessible wireless technologies in use today, namely; WiMAX, LTE, Wi-Fi, ZigBee, Bluetooth, EV-DO, NFC, HSPA, 3G standards, satellite services etc. [1]. The advancement route of wireless mobile communication system is exhibited in figure 1.1. Most of the wireless technologies have mutual trade-offs, operate on cooperative principles and have common restrictions and performance criteria. All applications in the long course of time will be brought over wireless networks. Often it may so happen that some will be able to gain more access
than others. Wired applications are becoming extinct and regardless of vital technology and connectivity all applications should perform healthy and need to be error free.

Figure 1.1. Wireless Technology Advancement Path

1.2.2 Performance Criteria of Wireless Networks

There exists a different set of limitations and constraints of almost all types of wireless technology. All communication methods have a maximum channel capacity, irrespective of the particular wireless technology usage [5]. The mathematical model of Claude E Shannon is represented by equation 1.1. It is the basis of deciding the channel capacity.

$$C = B \log_2 \left( 1 + \frac{S}{N} \right)$$

(1.1)

where, $C$ is the channel capacity (bits/sec.), $B$ is the available bandwidth (Hz), $S$ is the average received signal power and $N$ is the average power of noise (watts or volts$^2$).

The attainable data rates depend upon the amount of available bandwidth (BW) and the signal power. BW and signal power are the main performance criteria’s which governs the channel capacity and are explained below.
• **Bandwidth (BW)**

Bandwidth of a network is the frequency range which allows smooth communication to take place between the devices, viz. 2.4 to 2.5 GHz band is used by 802.11b and 802.11g standards across all Wi-Fi devices [5]. The frequency range and its allocation are decided by the local government as per the guidelines laid down by the International Telecommunication Union (ITU), for example; spectrum management and regulation in India is the joint responsibility of more than one body under the Ministry for Communications and Information Technology (MoCIT). Different spectrums may be allocated to the same wireless technology used in different countries. Some of the frequency spectrum for different types of Radio services allocated in India by National Frequency Allocation Plan (NFAP) is presented in Table1.1.

<table>
<thead>
<tr>
<th>Frequencies</th>
<th>Potential Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1GHz &amp; 2.3 GHz</td>
<td>3G broadband</td>
</tr>
<tr>
<td>2.5 - 2.7 GHz</td>
<td>WiMAX, Satellite based mobile and broadcasting applications, such as for national emergencies and natural disasters.</td>
</tr>
<tr>
<td>5.15 - 5.35 GHz and 5.725 - 5.775 GHz</td>
<td>These are unlicensed spectrum bands and are free for indoor applications. Used in Wireless local area networks, metropolitan access networks, wireless ISPs.</td>
</tr>
<tr>
<td>2400 - 2483.5 MHz</td>
<td>Wi-Fi and Bluetooth for short range services</td>
</tr>
<tr>
<td>1710 - 1930 MHz</td>
<td>GSM services</td>
</tr>
<tr>
<td>806 - 960 MHz</td>
<td>GSM and CDMA mobile services</td>
</tr>
<tr>
<td>3600 - 10000 Hz</td>
<td>Space research, radio navigation etc.</td>
</tr>
</tbody>
</table>

As per the model of Shannon the average channel bit rate is directly related to the assigned frequency range. Therefore, by doubling the frequency range the data rate will be doubled with remaining parameters being same. Also, all the range of frequencies does not provide the same performance; high frequency signals cannot
travel for longer distance covering a small area (micro cell), but can transfer more data and require large infrastructure. Whereas, low frequency signals can travel longer distance covering large areas (macro cells), but require large size of antennas and also more number of users will be accessing. For some of the applications a particular range of frequencies are of more significant than others. Low range of frequency are suitable for broadcast applications. On the other hand, smaller cells are favorable for two-way communication providing larger BW and less competition [5].

- **Signal Power**

  Signal power between the sender and receiver i.e. signal power to noise power is also an essential limiting factor in all wireless communications. To achieve the preferred data rate in presence of huge amount of background noise, the transmitting information signal power has to be augmented [5]. The other undesirable devices may generate detrimental interference while communicating over a common wireless medium. Other wireless devices accessing a common network may generate interference due to near far effect and/or cell breathing. These effects are shown in figure 1.2 a. and 1.2 b [5].

  - Cell Breathing is a situation in which the coverage area expands and shrinks based on the accumulative noise and interference levels.
  - Near Far Effect is a situation in which a receiver receives a strong signal which makes the receiver difficult to distinguish a weaker signal.

![Figure 1.2.](image)

**Figure 1.2.** (a) *Cell Breathing* (b) *Near-Far Effect*
The performance of any wireless network is restricted by the factors such as signal to noise ratio (SNR) and the assigned bandwidth (BW) [5].

All radio driven communication is [5]:
- Made over a shared communication medium (radio waves).
- Regulated to use particular BW and frequency range.
- Regulated to use particular transmit power rates.
- Based on continuously fluctuating background noise and interference.
- Based on technical limitations of the preferred wireless technology.
- Based on device limitations such as power capacity, form factor etc.

Wireless technologies are designed for transmitting data at maximum rate, for example; 802.11g standard is proficient for transmitting at 54 Mbit/s data rate, 802.11n standard is capable of transmitting up to 600 Mbit/s and Long term evolution (LTE) standard up to 200 M bit/s [5].

Few factors which may affect the performance of wireless network are [5]:
- Space between receiver and sender.
- Background noise in present location.
- Interference from users within the same network (intra-cell).
- Interference from users in the neighboring networks (inter-cell).
- Power capacity of sender and receiver.
- Processing power and the selected modulation scheme.

Wireless performance is highly variable; with a small adjustment in the location of the receiver, one can increase the throughput to a greater extent at a specific time, and at the same time throughput could be reduced again when another receiver starts competing to access the radio channel.

1.3 HETEROGENEOUS WIRELESS NETWORK TECHNOLOGY

Set of devices are connected to one another in a network. There are many different technologies available for different applications and are accessible for use with various topologies and scales [5]. A method of classification based on geographic range is listed in Table 1.2 [5]. The classification shown in Table 1.2 is not exhaustive however; it is only aimed to illuminate the elite differences within each use case.
Table 1.2 Wireless Network Classification Based on Geographic Range

<table>
<thead>
<tr>
<th>Type</th>
<th>Range</th>
<th>Applications</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local area network (LAN)</td>
<td>Inside a building or campus</td>
<td>Extension of wired network using wireless media</td>
<td>IEEE802.11 (Wi-Fi)</td>
</tr>
<tr>
<td>Metropolitan area network (MAN)</td>
<td>Inside a city</td>
<td>Inter-network connectivity using Wireless media</td>
<td>IEEE 802.15 (WiMAX)</td>
</tr>
<tr>
<td>Wide area network (WAN)</td>
<td>Universal</td>
<td>Wireless access of network</td>
<td>Cellular standard (UMTS, LTE etc.)</td>
</tr>
<tr>
<td>Personal area network (PAN)</td>
<td>Few meters</td>
<td>Replacement of Cable for peripheral connectivity</td>
<td>ZigBee, Bluetooth, Etc.</td>
</tr>
</tbody>
</table>

Many technologies and standards start with a particular scenario, for example; Bluetooth got introduced for PAN applications as a replacement for cable with higher capabilities & throughput, and to communicate efficiently with IEEE 802.11 network for achieving higher bandwidth (BW) [5].

As an alternative for WAN and cellular networks, WiMAX got introduced for fixed wireless communication and was enhanced later for achieving mobility [5]. Different networks have different characteristics. Each of the standards endure to transform in order to obtain faster processes, improved battery capacities, superior algorithms, and further innovations will continue for enhancement of the wireless standards [5].

The influence for the emerging technology and current technology enrichment has come into existence because of the interest and demands of the user for advanced services [6]. Challenges in mobility management, increase in exposure area, quality of service, lesser cost for data transfer, increased power conservation during handover (HO), etc. are to be accomplished to fulfill the growing user requirements to access the services such as multimedia and data [6]. The currently existing different access technologies; WLAN, Wi-Fi, Wi-MAX, GSM, CDMA, GPRS, UMTS etc., provide diverse services having unequal coverage area, throughput, monetary cost etc., to the users [7]. The characteristics of these access technologies are listed in Table 1.3 [6].
Table 1.3 Characteristics of Wireless Access Technologies

<table>
<thead>
<tr>
<th>Network</th>
<th>Coverage</th>
<th>Data Rate</th>
<th>Mobility</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite</td>
<td>World</td>
<td>High data rate fixed services up to 155 Mbit/s</td>
<td>Very High</td>
<td>High</td>
</tr>
<tr>
<td>GPRS</td>
<td>35 Km’s</td>
<td>9.6 to 144 Kbit/s</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>EDGE</td>
<td>20 Km’s</td>
<td>160 to 200 Kbit/s</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Wi-Max</td>
<td>30-50Km’s (LOS); 3-10 Km’s (Non LOS)</td>
<td>72 Mbit/s</td>
<td>Average /High</td>
<td>Average</td>
</tr>
<tr>
<td>UMTS</td>
<td>20 km’s</td>
<td>42 Mbit/s with HSPA+</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>IEEE 802.11a</td>
<td>10 km’s</td>
<td>54 Mbit/s</td>
<td>Average</td>
<td>Average</td>
</tr>
<tr>
<td>IEEE 802.11b</td>
<td>200 to 500 meters outdoor 50 to 100 meters indoor</td>
<td>1 Mbit/s to 11 Mbit/s</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>HiperLAN2 Low</td>
<td>30 to 150 meters</td>
<td>54 Mbit/s (over the air-rate)</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>IEEE 802.11g</td>
<td>30 to 150 meters</td>
<td>20 Mbit/s</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Blue tooth</td>
<td>10 meters</td>
<td>700 Kbit/s</td>
<td>Very Low</td>
<td>Low</td>
</tr>
<tr>
<td>HiperLAN</td>
<td>100 meters</td>
<td>10-20 Mbit/s</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>IEEE 802.16a</td>
<td>25 to 30 Km’s</td>
<td>50 to 70 Mbit/s</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>IEEE 802.20</td>
<td>15 to 20 Km’s</td>
<td>1 - 9 Mbit/s</td>
<td>Very High</td>
<td>High</td>
</tr>
</tbody>
</table>

The users can have access to the networks of first generation (1G) to third generation (3G) which are designed for different available BW, coverage area, throughput, latency, and the access cost. The advancement in various wireless access technologies such as LAN 802.11, Wi-Max etc., with improved throughput, low
access cost as compared with the cellular network technologies such as GSM, UMTS etc. has made the fourth generation (4G) to come into existence [7, 8]. IP based non-real and real time applications are implemented in 4G so that IP services can be accessed from any network and from any location. Amalgamation of wireless technologies namely Bluetooth, WLAN, GSM, GPRS, UMTS and Wi-Max termed as “heterogeneous network” is achieved in 4G to provide IP services as depicted in figure 1.3 [7, 9]. In order to have access to additional access technology, numerous interface mobile devices has been introduced.

Always Best Connected (ABC) at any time and from anywhere with seamless mobility are the core challenges in 4G technology [10]. The concept of ABC allows the suitable user device to support the features provided by the access technologies such as cellular network, WLAN, WiMAX, Bluetooth, DSL, and ZigBee etc. [11]. The advancement in service area, throughput, latency, access cost etc., is the key focus of 4G technology.

Figure 1.3. Heterogeneous Network
1.4 CHALLENGES IN HETEROGENEOUS WIRELESS NETWORKS

Wireless networks in future could be established with IP background and will be using heterogeneous access technology. Future wireless system may be established to offer better quality of services (QoS) with higher data transfer rates and accomplish seamless mobility between the heterogeneous networks. As per the preference of users and for different kind of applications the heterogeneous networks will be accessed. Seamless vertical handover (VHO) is essential for better performance when connections are to be switched from one access technology network to another. The performance metrics such as network capability, latency, access cost, power consumption and user’s preferences etc., need to be considered for VHO making. Many challenging problems are to be resolved for providing seamless service. These issues are listed below [12].

1.4.1 Quality of Service (QoS) Based Issues

It is a measure of network performance based on the transmission quality and service availability. Number of parameters should be considered to offer best network services such that MN’s will be served with guaranteed QoS for real and non-real time traffic. It can be characterized by reliability, delay, jitter, and BW parameters.

1.4.2 Transmission Control Protocol (TCP) Performance Based Issues

TCP performance should be measured for congestion when switching takes place from high data rate network of lower BW to a low data rate network of high BW.

1.4.3 Security Based Issues

Sensitive data is to be transmitted in tenable manner, particularly in wide area network. Requirement of high level security demands, high priority in wireless network, particularly in applications such as m-commerce and e-commerce. Mobility of users in wireless network fundamentally makes the wireless network to be more secured. To make the user’s communication more secured, validation and data encryption techniques on the radio interface are used by the wireless network [12].

1.4.4 Signal Distortion and Attenuation Based Issues

Signals travelling over a wireless medium undergoes different phenomenon such as fading, reflection, diffraction, and scattering, resulting in a distorted and attenuated signal while receiving. This is to unprotected media which makes the reception unreliable resulting in substantial loss of packets.
1.4.5 Mobility Based Issues

In a wireless network a continuing link should not be dropped to support mobility. In an infra-structured network a protocol is required to make seamless handover (HO). In an ad-hoc network the transmission route is required to be recomputed to accomplish with the topological changes when a mobile host moves. In such an environment where network topology changes frequently, the design of a competent routing protocol is a great challenge.

1.4.6 Power and Energy Based Issues

In wireless mobile device there is limited availability of power source and has to be efficiently utilized to increase the life period of mobile device before the power is restored. As the process of restoring is difficult in wireless mobile devices, the power consumption may be reduced by decreasing the number of handovers (HO’s).

1.4.7 Data Rate Based Issues

In high speed applications such as multimedia, the required transmission data rate should be high enough. To achieve higher data rates, while designing the network components one should consider algorithms for data compression, error resilient coding for interference mitigation, power control, and the protocols for data transfer [12]. The main challenge is to improve the data compression algorithms by using efficient error control with little overhead to produce high quality audio & video, and to protect sensitive data from being corrupted. Also, by using high cognitive capacity protocols for data transfer, the throughput can be enhanced.

For accessing wireless mobile services without interruption, mobility management is one of the main challenge in the heterogeneous network. Vertical handover (VHO) management is one such challenge. VHO management for identifying the optimum vertical handover decision (VHD) making algorithm and to accomplish the requirements of users and service providers of the network, is one of the burning research areas in wireless network. Several methods are proposed in the literature, but still void prevails in terms of competent method which can provide QoS and accomplish the requirements of user and network [7].

1.5 MOBILITY MANAGEMENT IN HETEROGENEOUS NETWORK

In wireless networks of next generation, better mobility management process is required for effective service delivery to the mobile users by anticipating the location
of user [7, 13]. In order to design a communication protocol which can adopt to the situation, the different existing mobility management schemes need to be integrated. With increasing number of mobile nodes and with the integration of internet and wireless mobile communication, the mobility management need to be improved [13]. The mobility management empowers mobile terminal (MT) to switch between networks of better resource management for delivering data packets and maintain a mobile subscriber’s connection.

In 1992, working group of Internet Engineering Task Force (IETF) has introduced mobility at the network layer and is visible to higher level protocols such as TCP and applications [14]. The outcome of this is mobile internet protocol referred as Mobile IP4 (MIPv4) [14]. This concept of mobility was introduced at the TCP/IP network layer by means of two mobile node (MN) addressing techniques namely; Static home Address (HoA) used to identify the mobile node home location, and Care of Address (CoA) referred as IP Address (IPA) is used to recognize the present location of mobile nodes existing in foreign network. In order to support the mobility management in MIPv4, these addresses are linked with Foreign Agent (FA) and Home Agent (HA).

Due to more packet loss, large handover latency, and triangular routing etc. the MIPv4 is not much suitable for real time applications. In order to eliminate the problems of MIPv4, IETF implemented mobility as a vital feature in the next generation IP, referred as Mobile IPv6 (MIPv6). The triangular routing problem as observed in IPv4 is eradicated in MIPv6 while providing apparent packet’s routing between the mobile nodes when they are at bay from home network as depicted in figure 1.4 [15]. Also, the protocol complexity is decreased by using MIPv6 which is achieved by eliminating the Foreign Agent from the network architecture and generate the CoA with the support of mobile node. MIPv6 cannot manage seamless and efficient handover of mobile nodes at the network layer and hence worsens the overall performance, and thereby increases the packet delay and loss, and signaling overhead [15].

The different kinds of MIPv6 such as Fast-Hierarchical MIPv6 (FHMIPv6) [16], Hierarchical MIPv6 (HMIPv6) [16], Fast MIPv6 (FMIPv6) [17], and Proxy MIPv6 (PMIPv6) [18] are endeavored to resolve the handover problem in WLAN. The MIPv6 is governed by the network related parameter such as Received Signal
Strength (RSS). On the other hand the mobility management in vertical networks not only depends on network related, but also on the user, terminal and service related parameters.

![Mobile IPv6 Environment](image)

**Figure 1.4. Mobile IPv6 Environment**

Designing the mobility management for vertical (heterogeneous) networks is the key focus of researchers and the industry. To achieve smooth mobility, IETF used IEEE 802.21 standard Media Independent Handover (MIH) to make the vertical wireless access technologies independent of the network layer [19, 20]. This is achieved by registering the required handover information in the link layer and in the other network elements such as MIH_LINK-SAP (MIH_LINK Service Access Point) [21] and LLC_SAP (Logical Link Control Service Access Point), as shown in Figure 1.5 [20, 22]. It mainly addresses two challenges i.e. Location Management and Handover Management, in the congregated networks.
The capability to perform a function, and the issues of these activities are as follows:

1.5.1 Location Management

For successful delivery of information the location management has to trail the mobile terminal (MT). Mobile IP is likely to be the key engine for location management to facilitate seamless roaming in the next generation [2]. Location management comprises of location registration, and call delivery or paging. In the process of registration the mobile node sporadically sends clear signals to notify the network of its current location and also to update the location database. After registration, the procedure of call delivery is originated so that a call may be delivered magnificently based on the information congregated during location registration procedure.

Location management activates the network for delivery of call or for paging by ascertaining the present mobile user attachment point, as illustrated in Figure 1.6 [23]. In location registration step, the mobile node intermittently intimates the network about its new access point and there by consents the network for authentication of user and to update user location. In the call transfer phase the present position of the
mobile host is identified from the user location information as updated in the network [23]. Design of Database architecture and the signaling message communication between various elements of a signaling network are the present techniques used for location management [23].

![Diagram of Location Management Operations](image)

**Figure 1.6. Location Management Operations**

With increase in mobile users, novel or enhanced schemes may be required. Other issues such as delays in inquiry, security, methods of terminal paging, dynamic updates of database, and delays in paging should be considered for location management. Figure 1.6 portrays these research issues along with respective location management operation [23]. Location management deals with the issues such as database and signaling and hence most of the issues are not protocol dependent. Therefore, according to the need they can be attended in networks such as PLMN-based networks, Integrated Service Digital Network (ISDN), Frame Relay, IP, X.25, or ATM networks, Public Switched Telephone Network (PSTN) etc. [23].
Following are the main issues that are supposed to be addressed while designing Location Management schemes [2]:

- Signaling overhead minimization.
- Minimization of latency in the service delivery.
- To assure quality of service of the applications.
- Design of an competent and robust algorithm;
  - To select the best network by mobile node to perform registration.
  - To decide how often and where the location information must be kept, and how to manage the precise location of a mobile node within the exact time frame in a completely overlapping area where a number of wireless networks co-exist.

1.5.2 Handover Management

Handover Management is essential to maintain the dynamic links for wandering mobile nodes because they change their network point of attachment [24]. Generally mobile devices and network technologies are designed based on the user and service needs. Some of the examples which experience incredible applications and convention include; 2.5G to 4G cellular systems, satellite network, WLAN, ZigBee, WiMAX and Bluetooth networks [24]. These networks must provide enough BW, coverage area, data (text, voice and video), and security on the whole for the mobile users. When a mobile user leave his current network coverage area and moves into a nearby network area or selects a superior network based on user preference, transfer has to take place impeccably without the awareness of the mobile user. The stimulating task for such a handover depends up on; when the network decides to handover? How to achieve smooth handover? And of course how to select a best network when choice is available?

In all the IP based succeeding generation wireless networks, the design of VHO management techniques need to attend the following issues: (i) Reduction in the signaling overhead and power consumption for processing the handover. (ii) Uphold the connection to minimize packet loss and transfer delay (iii) Maintain the preferred QoS, (iv) Efficient exploitation of the network resources, (v) Handover process must be scalable, trustworthy and robust, (vi) VHO process must provide validation of the mobile users [2].
1.5.3 Open Issues in Location and Handover Management

Design of proficient mobility management techniques will play a significant role to provide seamless services in future wireless networks. Following are the substantial issues which will play leading role in the mobility management [2].

- **QoS Based Issues**
  IP based wireless networks must offer assured QoS to mobile terminals in future. Location management for delivery of timely services, efficient access, QoS based negotiation during inter system handover etc., will convey novel issues to the mobility management [2].

- **User Nodes Based Issues**
  Design of single user node which can operate autonomously in diverse networks having different access technology (Heterogeneous Networks) will be another important issue. In order to offer better user services such as data, location, and context–aware multimedia services, a node must use copious information available for e.g. communication with nearby systems, cross-layering with network elements etc. This information will be useful user node re-configuration [2].

- **Mobility Management in Overlay Networks Based Issues**
  Access networks with varying coverage areas may be tiered in upcoming wireless networks. Location management and handover management in these networks will be one of the noteworthy issues [2].

- **Mobile Services in Heterogeneous Networks Based Issues**
  To provide user services in a better way, the 4G service innovation techniques will cartel the location information and context-awareness. For providing bespoke services in different operating environments to a user node, requires more intricate personal and session mobility management. Should service initiation protocol (SIP) be the vital 4G protocol, and the service providing framework shall be network or application layer-based, is even today an undefined issue [2].

- **Optimization of Cross-Layer Based Issues**
  For development of novel mobility management schemes, the cross-layer-based design approaches will be useful in upcoming heterogeneous wireless network [2].

- **Different Other Issues**
  In subsequent generation heterogeneous networks, convenience of network
services, fault tolerance, security enhancement, intellectual packet routing, call routing, intelligent discovery of gateway, efficient selection procedures, integrated protocol design and integration mechanisms of vertical protocol are few of other vital issues [2].

1.6 VERTICAL HANDOVER IN HETEROGENEOUS WIRELESS NETWORK

VHO is a process of retaining a user’s continuing session when a mobile node changes its connection from one access network to another [24]. Control signaling is identified by the process of handover which is assisted by the algorithm used for making handover decision so as to accomplish the handover. Handoff is the generally used term in American English and Handover in British English. Handoff term is used by American organizations such as 3rd Generation Partnership Project 2 (3GPP2) and Code Division Multiple Access 2000 (CDMA2000). Handover is used within European organizations such as International Telecommunication Union - Telecommunication Standardization Sector (ITU-T), Internet Engineering Task Force (IETF), 3rd Generation Partnership Project (3GPP), and European Technical Standards Institute (ETSI), and is standardized within European originated standards such as Global System for Mobile Communication (GSM) and Universal Mobile Telecommunications Systems (UMTS). The handover term is commonly used in academic research publications and literature, while handoff is generally used in the organizations such as Institute of Electrical and Electronics Engineers (IEEE) and American National Standards Institute (ANSI).

Vertical handover (VHO) brings up transformation in connectivity of a network terminal from one network to another network of not the same access technology (Heterogeneous Network) as per the user preference, and to support the node mobility [25]. For example, to access an internet a mobile phone is capable of using a cellular technology and a wireless LAN. The mobile phone user prefer to connect to a wireless LAN if available because of high speed of LAN, and will switch over to a cellular network in absence of wireless LAN.

Due to the advantages of utilizing large bandwidth (BW), lesser cost of WLAN and improved mobility support with more coverage of UMTS, VHO’s between WLAN and UMTS (WCDMA) is one of the evolving research area
in 4G wireless networks [10]. VHO’s among unlike wireless and wired access technologies can be attained using MIH (IEEE 802.21) [20].

1.6.1 VHO Process
The VHO in heterogeneous networks experiences three different phases as listed below. The process is presented in figure 1.7 [13, 23, 24 & 26];

- **Initiation Phase**
  In this phase, the handover is either initiated by the network agent, a mobile device, or by fluctuating network conditions. Initiation of Handover is made in suitable time after collecting information’s like Received Signal Strength (RSS), Bandwidth, Link Speed, Jitter, Throughput, Monetary Cost, Power Consumption, Latency, Network Subscription, and User Preference etc. from Link, Transport, and Application Layers [23, 24 & 26].

- **Decision Phase**
  In this phase, network should identify novel resources for establishing a connection and bring about any further routing operations required, based on the user preferred decision making parameters [23, 24 & 26].

- **Execution Phase**
  During this phase the existing network connection should be transferred to another network in a smooth way. It comprises; flow control of data to maintain the desired QoS, Approval, Validation, and transfer of user’s background information [24, 26].

  The research related issues of handover processing are presented in figure 1.7 [23], and are namely: proficient and convenient processing of packet; decreasing the network signaling load; optimizing the path for each connection; efficient bandwidth reassignment; evaluating current methods for standardization; and improving QoS for wireless connections [23].

1.6.2 VHO Classification
Handover of a mobile terminal to another network of homogeneous or heterogeneous access technology can be classified as illustrated in Figure 1.8. Handover classification is made based on different issues namely; type of network, number of connections, frequencies, administrative areas, handover necessity and control of user in the handover process [24 - 26].
1.6.2.1 Classification Based on Network Types Involved

Depending on the access technology involved (homogeneous or heterogeneous), the handovers could be classified as Horizontal or Vertical Handover [25, 26].

- **Horizontal Handover (HHO)**
  
  HHO’s in homogeneous networks are known as HHO’s (intra-system handovers), where in HO takes place between the networks having alike access technology. Such type of HO take place when the received signal strength is lesser than a well-defined threshold value [25, 26]. For example, switching the connectivity from GSM base station to an adjacent GSM base station as the mobile node moves around.

- **Vertical Handover (VHO)**

  Handover between networks of different access technology (Heterogeneous Networks) is known as vertical handover (inter-system handover) [25]. VHO in heterogeneous wireless networks will occur;
  
  - If a user goes out of the serving network area and enters in to an overlying network area.
  - If a mobile node needs to handover to an overlaid or under laid network to fulfil the desired service requirements.
If the overall load on the network is required to be distributed among different systems.

Heterogeneous wireless networks differ in access technology used, exposure area, routing techniques, and mobility management. Also, different services are offered by different operators as per the user need (Voice, data, multimedia, text etc.) [25].

Further VHO can be classified as upward and downward handover. In upward HO, the HO takes place from network of smaller exposure area to a network of larger exposure area and in downward HO the HO takes place from larger exposure area network to a smaller exposure area network [25].

![Diagram: Classification of Handover](image-url)

**Figure 1.8. Classification of Handover**
1.6.2.2 Classification Based on Number of Connections Involved

Based on the number of serving network nodes accessed during the handover process, VHO can be classified as soft, hard, and softer. This may well be made possible due to the introduction of new mobile devices which can support multiple interfaces.

- **Hard Handover (Break before make)**

  The Connection to existing network is released and then handover takes place to entrant network in hard handover. It is advantageous as only one channel is used per call at any instant of time and it doesn’t require multiple channels in parallel to receive the same call and hence inexpensive & simpler. The hard handover event is usually not noticeable by the user and is very short. In analog systems the handover can be witnessed as a very short tone whereas it is unnoticeable in digital systems. The drawback is that the call may be momentarily interrupted or terminated abnormally if the handover fails [25, 26]. Hard handover is mainly used in time division multiple access (TDMA) and orthogonal frequency division multiple access (OFDMA) in which different frequency series are used in neighboring channels so that channel interference can be reduced. Therefore, when a mobile node moves from one serving network node to another serving network node, then it is impossible for it to communicate with both the serving nodes, due to difference in usage frequency.

- **Soft Handover (Make before break)**

  In soft handover, the handover to candidate network takes place initially and then the connection of the previous network is released. Soft handover can further be classified as; multi way soft handovers and softer handovers. One of the benefits of such a handover is that the source network connection is terminated only when a reliable target network connection has been established and hence the probabilities of abnormal call termination due to failed handovers are lower. Another benefit is that the channels in multiple cells are maintained simultaneously and the call can fail only if all the channels fade or interfered at the same time. The likelihood of fading and interference taking place at the same instant in all channels is very low, as both in different channels are unrelated. Therefore for a call in a soft handover, the steadfastness of the connection turn out to be higher. The main drawback of soft handover is that the mobile node hardware is more complex, as it has to process
numerous channels in parallel. Another shortcoming of soft handover is the deterioration in number of residual free channels and the capacity of the network, which is due to the usage of multiple channels in the network for a single call.

- **Softer Handover**
  
  Softer handover is analogous to a soft handover, except that the mobile terminal changes its connection within the same access points.

**1.6.2.3 Classification Based on User Control Allowance**

Based on whether or not a user has a control on handover, VHO can be classified as passive, proactive, imperative and alternative [25, 26].

- **Proactive Handover**

  User is permitted to decide when to handover in proactive handover mode. Based on the number of preferences identified by the user, the handover decision can be taken. Proactive handover is anticipated to be as one of the most vital feature of the 4G wireless networks.

- **Passive Handover**

  In passive handover, the user does not have any control over the handover process. It is generally used in 1G, 2G and 3G wireless systems.

- **Imperative and Alternative Handover**

  In imperative handover the handover takes place when the received signal strength (RSS) becomes indistinguishable, and in alternative handover the handover is initiated to offer the user with improved performance with respect to the accessing cost of the network and QoS as per user preference and the application requirement.

**1.6.2.4 Classification Based on Requisite of Handover**

Depending on whether handover is essential or optional it can be categorized as voluntary and obligatory handover.

- **Obligatory Handover**

  In order to circumvent discontinuation of current communication link, it is vital for a mobile node to make handover to another access point from the existing one. Such a handover is demarcated as obligatory handover.

- **Voluntary Handover**

  In few situations, the HO of current connection is optional. Such a HO is defined as voluntary handover and in such circumstances the QoS may or may not improve.
1.6.2.5 Classification Based on Administrative Domains Involved

The group of different networks and systems operated by administrative authority, lie under this group. Diverse networks controlled by different administrative authorities will be existing in 4G wireless networks and hence administrative domains play a notable role in 4G wireless networks [25, 26].

- **Intra Administrative Handover**
  
  Handover technique in which a mobile node switches between different homogeneous or heterogeneous networks, managed by the same administrative province is titled as intra administrative handover.

- **Inter Administrative Handover**
  
  Handover technique in which a mobile node switches between different homogeneous or heterogeneous networks, managed by different administrative provinces are titled as inter administrative handover.

1.6.2.6 Classification Based on Channel Frequencies Used

Handover techniques in which a mobile node switches from one signal frequency channel to another can be classified based on whether or not the switched channel frequency is same or not. Handover can accordingly be categorized as intra-frequency or inter-frequency handover [25, 26].

- **Intra-Frequency Handover**
  
  Handover technique in which a mobile node switches between access points operating on the same frequency is defined as intra-frequency handover. For example, CDMA – FDD network systems.

- **Inter-Frequency Handover**
  
  Handover technique in which a mobile node switches between access points operating on different frequency is defined as inter-frequency handover. For example, CDMA-TDD, GSM network systems.

1.6.2.7 Classification Based on Controlling Node Involved

Handover are either controlled by the mobile terminal or the network terminal and accordingly handover can be categorized as mobile controlled handover (MCHO), network controlled handover (NCHO), mobile controlled network assisted handover (MCNAHO), and network controlled mobile assisted handover (NCMAHO) [24]. Different approaches are used in different systems to accomplish handover which are
described by handover protocols. Based on the measurement, handover decision is originated & is accomplished. The mobile node unceasingly measures received signal strength in existing channel and is compared with other channels. Based on handover control protocol the handover decision making mechanism may be categorized as centralized or decentralized. This classification is made based on whether the handover decision is taken by mobile node, network node or the association between them [9].

In MCHO, handover mechanism is fully controlled by the mobile terminal. Such handover process undergoes with short response time (0.1 second) [9]. Mobile node measures the received signal strengths and intensity of interferences of all the nearby channels and a handover can be initiated if the received signal strength from the current network node is lesser than that of neighboring network node by a predefined threshold value [9].

In the process of NCHO, handover decision is made by the current network node based on the signal strength measured at different other serving network nodes. The handover process which comprises of data transmission, channel switching, network switching etc., may take 100–200ms. NCHO technique is used in the analog systems of first generation namely; NMT, AMPS and TACS.

In NCMAHO process, the measurement is made by the mobile terminal and the decision is made by the network. In the circuit switched GSM, the BSC is responsible for the radio interface management, i.e. allocation and release of radio channels and handover management. The response time is approximately one second.

In MCNAHO the network node makes the measurements and the mobile node makes the decision. Such handover processes are more appropriate because of consideration of user preferences for handover decision making.

1.6.3 VHO Prioritization

The probability that the handover will not be served is equal to blocking probability of new originating call in systems which handle handover, in same way as they handle new originating call. In order to avoid abrupt termination of ongoing call in such systems, handover request should be given priority to new call and is called as handover prioritization. There are two techniques of assigning priority [27].
• **Guard Channel Concept**
  A portion of the total available channels in a cell is earmarked solely for handover request for an ongoing call in such technique.

• **Queuing**
  Queuing of HO’s is possible due to finite interval of time between the time the received signal level drops below HO threshold and the time the call is terminated, because of inadequate signal level. The delay size between HO threshold level and the call drop is determined from the traffic pattern of a specific service area. The guard channel and queuing patterns often reduce the HO call blocking probability but with increase in the probability of new call blocking (PNCB), and HO delay. Lan Wang in [28] suggested a HO scheme which can vigorously manage the reserved channels to be used for handover calls as per the present status of the HO queue and hence improve the performance of guard channel and queuing patterns and thereby reduce blocking probability of new call and HO delay.

### 1.7 DESIGN OBJECTIVES OF VERTICAL HANDOVER MANAGEMENT SCHEMES

The Design objectives of handover management schemes are listed as [6]:

- In order to circumvent the mobile terminal from going through any kind of service degradation or interruption, the algorithm designed for handover process should be very fast.
- For reasonable service and to improve communication features and reduce the total time used up on handovers, the total number of handovers required should be scaled down.
- Information loss during the handover process should be reduced to the least possible extent.
- Blocking probability of new call should be reduced.
- During the process of handover the power consumption should be minimum.
- Network resources should be competently utilized.
- Handover algorithm should give priority to the user’s penchant and should be context aware.
- Once the handover takes place, the services offered should be reasonable.
- Handover algorithm designed must be secured, flexible, and scalable.
1.8 VHO DECISION MAKING PARAMETERS

In homogeneous networks, decision of handover is principally based on RSS (Received Signal Strength). For example, handover between cellular networks when the mobile node is in the overlapping area of two cells. Whereas handover process is more complex in heterogeneous networks. Two wireless networks operating with different access technology, generally have unequal signal strength, for example; Wi-Max and UMTS. Handover metrics in such environment may include BW, RSS, throughput, user preference, network conditions, application types, monetary cost etc.

VHO can be originated for the convenience of user instead of connection reasons [24]. VHD making algorithm improves the performance of handover when numerous static and dynamic parameters or combination of them are considered for decision making. Larger the number of parameters considered for decision making larger will be the decision time and more complexity of the algorithm. In order to make a mobile node behave in an efficient way it is required to cautiously monitor the performance metric information and use a suitable policy for using these metrics for making correct handover decision. The performance metrics based on the frequency and location information, can be characterized as static or dynamic [29]. The various static and dynamic parameters are listed below and are also depicted in figure 1.9 [6, 24 and 27].

- **Network Related Parameters**
  Available BW, HO latency, RSS, signal to interference ratio, cost, security, estimated time, power dissipation, average number of requests made per unit time, number of networks under evaluation, threshold bandwidth, and average number of calls attended in unit time etc. are few of the network related parameters, used for making handover decision [24].

- **Terminal Related Parameters**
  Location information, power consumption, velocity, etc. are some of the terminal related parameters considered for making handover decision [24].

- **User Related Parameters**
  The parameters such as user preferences and user profile are the user related considered for making handover decision [24].
- **Service Related Parameters**

  The parameters such as service capacities, QoS etc. are some of the service related parameters considered for making handover decision. These parameters are also classified as static and dynamic parameters. Static parameters are Security, Cost, Power Consumption, and dynamic parameters are Throughput, BW, Latency, RSS, User Preferences, Bit Error Rate (BER), Reliability, Velocity, and Network Load Balancing. Each of these parameters are briefly explained below [24].

  - **Bandwidth**

    BW has to be increased to accommodate more number of users for accessing the network, and to decrease the call blocking and dropping probability.

  - **Power Consumption**

    Power consumption has to be reduced, as more amount of power is used up due to frequent handovers. If it is not taken care of while designing handover techniques, there is extensive amount of battery drainage.

![Figure 1.9. Decision Making Parameters](image-url)
Handover Latency

It is the time intervened between the initiation of handover and successful completion of handover. This metric is considered while designing handover techniques for QoS improvement.

Network Cost

While designing handover algorithms considering multiple parameters for decision making, the cost parameter also has to be considered in few situations so as to reduce the cost of accessing the network.

User Preferences

User may choose a particular network based on the network performance, preference, and service types such as voice, video, data, and quality of service etc., and application requirements such as non-real and real time [24].

Network Throughput

The average transmission rate of data for successful delivery over a communication link in a network is referred as network throughput [24]. It is always appropriate to make handover to a network having higher throughput. To increase network throughput, dwell timer can be used [30].

Network Load Balancing

For achieving efficient HO and to reduce deterioration of QoS, the network load should be well balanced. Considering the classification mobile nodes based on the number of resources namely; resource-rich mobile nodes and resource-poor mobile nodes, the handover decision can be made by comparing the dynamic new call blocking probability (DNCBP). This metric can be used to specify network traffic load [31]. Higher the DNCBP value of a network, larger will be the network traffic load. To improve network throughput and to reduce the probability of new call blocking (PNCB) value and the handover dropping rate (HDR), HO to a network with lesser DNCBP should be made [31].

Network Security

To accomplish the highest levels of authentication, confidentiality, and integrity, the handover schemes should take care of network security features [24].

Received Signal Strength (RSS)

For proper reception of information at the receiving mobile node, the signal must
be strong enough between the user and the serving network node. The received signal strength must be above certain threshold level; else handover should take place as and when it falls below the threshold level. RSS based handover is a traditional handover initiation technique [24].

- **Velocity**

  Repeated occurrence of handover (ping pong effect) in a small network area for short duration of time, while a mobile node is moving at high speed in overlaid heterogeneous networks is not desirable. Thus the network and the handover model should be proficiently designed considering both dynamic and static metrics in such situation.

### 1.9 VERTICAL HANDOVER DECISION MAKING ALGORITHMS

The decision about how and when to change the network interface is centered on handover performance metrics. Handover algorithm are normally based on enhanced service, higher throughput and lower cost, etc. while some others, use fuzzy logic, artificial neural network or MADM methods to resolve the problem [24].

#### 1.9.1 Classification of VHD Algorithms

The VHD algorithm may be classified considering the handover decision making metric and the approaches used to process them [32 - 35]. The classification is as follows.

- **Received Signal Strength (RSS) Based Algorithms**

  Received signal strength is one of the vital decision making metric for handover. Various approaches such as RSS with Threshold, RSS with Hysteresis, RSS with Threshold and Hysteresis, and Prediction Technique, are used for handover decision making [36 - 40].

- **Bandwidth (BW) Based Algorithms**

  Available BW for a mobile node is the key metric in BW based algorithms [39, 41 and 42]. Both BW and RSS metrics are used for handover decision making in some of the algorithms [36, 43]. An algorithm may be categorized as RSS based or BW based algorithm depending on the key performance metric considered for decision making.

- **Cost Function Based Algorithms**

  Metrics such as security, BER, monetary cost, handover latency, BW, and power consumption etc., are considered together in cost function based algorithm to make
These metrics are weighted based on the user preference and network conditions before combining. Wei Shen and Qing-An Zeng in [48] proposed a cost function for either network selection algorithm or vertical handoff decision algorithm to evaluate the cost to use any type of network. The cost for using a network is based on factors namely; traffic load and RSS. The network having highest cost is selected as suitable network. Doo-Won Lee in [49] proposed a scheme with adaptive hysteresis to form simple cost function by means of some significant factors such as, velocity of user equipment (UE), difference in load between the target and serving network nodes, and service type. These factors are associated with handover failure rate (HFR) performance.

- **Combination Algorithms**
  These VHD algorithms are used to take handover decision for enhanced performance based on different input metrics, user preference and network requirement. It is generally very challenging to develop analytical formulations of handover decision process, while numerous performance metrics are considered in combination [50, 51].

- **Multiple Attributes Decision Making Algorithms (MADMA)**
  These algorithms calculate the measurable value of each and every normalized feature and assesses the target systems using the weighted function of the measurable values. There after the final decision is taken [52].

- **Authentication Based Algorithms**
  In order to get access to the other networks, the user has to use multi-pass validation measures in authentication based algorithms [53, 54]. This process leads to over loading of the authentication server and hence upturns the user authenticating delay. This is due the fact that there is a needless and frequent procedures and protocols. These algorithms provide proactive handover and authentication process and thereby maintain QoS and also reduces the handover delay.

### 1.9.2 Performance Evaluation Metrics for VHD Algorithms

Following are the metrics considered for measuring the performance of handover based on the usage scenario [55]:

- **Call Blocking Probability**
  It is the probability of blocking an attempt made by a newly initiated call. This
happens because of repeated occurrence of handovers when the number of frequency channels is limited.

- **Handover Blocking/Failure Probability**
  It is the probability of blocking an attempt made for handover. Failure of handover attempt happens when it is initiated but is not completed due to inadequate resources, or when the mobile terminal travels out of the target network serving area, before the process is completed. In the earlier circumstances the handover failure probability depends on the availability of channel in the target network, while in the latter circumstances it is governed by the user mobility [56].

- **Handover Probability (HP)**
  The probability that an ongoing call is in need of HO before the call is terminated while communicating with a particular serving node is referred as HP. This metric gives information about the average number of HO’s per serving node [56].

- **Call Dropping Probability**
  It is the probability of call termination when handover fails. Call blocking probability metric can be calculated from the metrics such as handover probability and the handover blocking probability [56].

- **State Dependent Probabilities**
  State dependent rejection scheme (SRS) is used as a common framework for analyzing current handoff schemes and for designing new ones using the suitable set of state dependent probabilities [57]. The Markov analysis of SRS can be used for making preliminary conclusions on handoff strategies. Authors in [57] concluded that SRS can adapt to different mobility and load scenarios and accomplish better performance while targeting QoS metrics.

- **Unnecessary Handover Probability (UHP)**
  The probability that a handover is initiated though it is not required is referred as UHP. Such repeated handover occurrence is termed as ping pong effect [41].

- **Missing Handover Probability (MHP)**
  The probability that a handover is not originated though it is required is referred as MHP [41].

- **Wrong Decision Probability (WDP)**
  The probability that a wrong decision is taken for making handover is referred as
WDP. It is summation of UHP and MHP [41]. Evaluation of wrong decision probability (WDP) guarantees a compromise between enhancement of network performance and reduction in ping-pong effect [41, 58 and 59].

- **Duration of Interruption**
  It is the time span during which the mobile node is not communication with any of the access node while making a handover.

- **Handover Delay**
  It is the time duration between the initialization and execution phase of the handover process [7]. Complexity of the VHD process is increased with increase in handover delay. Handover delay should be kept low for delay sensitive sessions such as video, voice, and data.

- **Number of Handovers/Rate of Handover**
  Repeated handovers per unit time will overload the network and network resources will be squandered A handover is well thought-out to be unnecessary while a mobile terminal handovers back to the earlier serving node in short duration of time [60, 61]. Such unnecessary handovers (UHO’s) should be minimized.

- **Throughput**
  It refers to the rate at which the data is delivered to the target node. Handover to a candidate network having greater throughput is desirable.

### 1.10 RESEARCH OBJECTIVES

In the present research we have set the following as research objectives:

- To review research activities in the area of VHO algorithms and state of art.
- To understand and infer the limitations of VHO algorithms for two node and three node network models found in research literature.
- To understand and infer the limitations of VHO algorithms for single and four state models.
- To analyze probability based formulation of five node network model for single state model.
- To improve prediction accuracy by modeling with four states in which the mobile node exist.
- To develop the solution for BW based algorithms for single and four state models.
• To extend the solution to BW+RSS based algorithms for single and four state models.
• To compute various probabilities like UHP, MHP, WDP and HP in single and four state five node network for validating VHD making algorithms, under BW and RSS criteria.

1.11 METHODOLOGY OF RESEARCH WORK
The research stages adopted in the methodology are as given below
• Conduct extensive survey of literature available in national and international journals, conference proceeding, text books, hand books etc.
• Understand the limitations of algorithms surveyed based on different performance criteria’s.
• Develop new probability models addressing improvements in handovers.
• Develop simulation models in MATLAB for the single and four state models.
• Simulate and test the code with single and combinational performance metrics.

1.12 RESEARCH CONTRIBUTION
WDP based algorithms are robust in terms of analytical approach and mathematical formulation and are independent of the technology used for the handover [41]. Wrong decision probability based analysis is used to compare different VHO decision making algorithms. This technique of probability modeling used is only applied to small scale network by using two and three node network in literature. In next generation, it is expected that the number of integrated networks available may be more in number, have higher BW and may be of different access technology. User can have access to any network in the vicinity as per his preference. This motivated the present research, to apply the technique of probability modeling to large scale network having large bandwidth under different states of mobile node such as cooperative state, failed state, selfish state and malicious state. We have analyzed the VHO algorithms that are based on performance metric such as BW and BW combined with RSS.

In this research work, a closed form solution using single state analytical model considering mobile node in cooperative state is obtained for a five node network. Simulation is carried out for a BW and BW plus RSS criteria based general algorithm. Additionally, an analytical model considering four states namely; cooperative state,
failed state, selfish state, and malicious state, for five node network is obtained. Simulation is further carried out for a BW and BW plus RSS criteria based general algorithm.

The results of five node network model considering BW as performance metric with single and four states of mobile node are shown with significant improvement in MHP, UHP and WDP. These models are compared with two and three node network models. Analysis is further done considering BW plus RSS as performance metric with single state and four states of mobile node and the results show significant effects of combination of metrics. Computational difficulties in evaluating the probabilities for the large BW networks are explained along with limitations.

1.13 THESIS OUTLINE

In Chapter 2, the literature corresponding to VHD algorithms and techniques to analyze them for seamless handover, based on user and network preference is presented. Also the literature survey regarding the research work happened in terms of analysis of VHO decision making algorithms based on probability modeling, network scale and occupied bandwidth are presented and gaps are identified.

In Chapter 3, closed form probabilistic analytical model using single state and four states of mobile node, to predict MHP, UHP, HP and WDP in a five node network is presented. Analytical modeling based on the gaps is identified.

In Chapter 4, solution for bandwidth based algorithms is developed using single and four state five node network model. The HP’s, MHP’s, UHP’s and WDP’s are computed for a general algorithm based on the BW as performance criteria. These models are computed and are used to predict the probabilities at different decision times and for large bandwidth channels using single state and four state model. Further, bandwidth based single state five node network model analysis results are compared with two and three node network and four state five node network model. Comparative results are plotted and conclusions are drawn.

In Chapter 5, solution for BW+RSS based algorithms is developed using single and four state five node network model. The HP’s, MHP’s, UHP’s and WDP’s are computed for a general algorithm based on the BW+RSS as performance criteria. These models are computed using MATLAB, and are used to predict the probabilities at different decision times and for large BW channels using single state and four state
model. Further BW+RSS based results are compared with BW based single state and four state five node network models. Results are plotted and conclusions are drawn.

In Chapter 6, Summary, Conclusions and Future directions are presented. Research literature on vertical handover decision making algorithms and the metrics used to evaluate these algorithms is presented in the next chapter.