A
Major - Project Report
On

A DYNAMIC DECISION MODEL FOR VERTICAL HANDOFFS ACROSS HETEROGENEOUS WIRELESS NETWORKS

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CERTIFICATE

This is certified that the major project report entitled "***A Dynamic Decision Model for Vertical Handoffs across Heterogeneous Wireless Networks***" is the work of ***Pramod Kumar Goyal*** (University Roll No. 10192), a student of Delhi College of Engineering. This work was completed under my direct supervision and guidance, and forms a part of the Master of Engineering (Computer Technology & applications) course and curriculum. He has completed his work with utmost sincerity and diligence.

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Pramod Kumar Goyal

Abstract

The convergence of heterogeneous wireless access technologies characterizes the 4G wireless networks. In such network environment the user equipped with multiple network interfaces, would want to roam between different networks without any interruption in the running applications and services, in such a way that minimise the network usage cost.

For this, a seamless and efficient handoff between different access technologies (vertical handoff) is essential. However, the heterogeneous co-existence of access technologies with largely different characteristics creates a decision problem of determining the "best" available network at "best" time to perform an efficient handoff.

In this major project, we propose a *Dynamic Decision Model (DDM)* to decide the "best" network at "best" time moment to handoffs. The proposed dynamic decision model make the right vertical handoff decisions by determining the "best" network at "best" time among available networks based on, dynamic factors, such as "Received Signal Strength(RSS)" of network and "velocity" of mobile station, as well as static factors such as "Offered bandwidth", "Power Consumption" and "Network usage cost". This model not only meets the individual user needs but also improve the whole system performance by reducing the unnecessary handoffs.

The proposed model is successfully developed, simulated and analyzed for a heterogeneous network consisting WLAN, CDMA and GSM networks.

Abbreviations

2G	2nd Generations, Currently available digital communication networks, e.g. GSM, CDMA
2.5G	2.5th Generation. Upgrades to currently available communication networks, bringing more bandwidth and, where not available, packet-based network e.g. GPRS
2.75G	2.75th Generation - A set of upgrades for 2.5G networks allowing for greater bandwidth, e.g. EDGE
3G	3rd Generation - Mobile technology according to IMT-2000 standard, e.g. CDMA 2000, W-CDMA, UMTS
AP	Access Point –associated with wireless LAN
Bluetooth	Chip technology enabling seamless voice and data connections between wide ranges of devices through shot-range digital two-way radio
BS	Base Station – associated with cellular network
CDMA	Code Division Multi Access
CDMA2000	North American version of IMT-2000, a 3G technology
DECT	Digital Enhanced Cordless Communications
DSL	Digital Subscriber Line- allows high-speed data communication over the existing copper telephone lines between end-users and telephone companies.
EDGE	Enhanced Data for GSM Evolution
GPRS	General Packed Radio System
GSM	Global System of Mobile communication – leading 2G standard
HHO	Horizontal Handover
HSCSD	High Speed Circuit-Switched Data
IEEE	Institute of Electrical and Electronics Engineering
LAN	Local Area Network
MMS	Multimedia massaging service- A successor to SMS
MSN	Microsoft Network

MT	Mobile Terminal
PDA	Personal Digital Assistant
PDC	Personal Digital Cellular
QoS	Quality of Service
SIM	Subscriber Identification Module - Smart card holding the user's identity and telephone directory; SMS application may reside of the SIM.
SMS	Short Massage Service - Facility for sending text massages on GSM Handset
TDMA	Time Division Multiple Access
UMS	Unified Massaging Service.
UMTS	Universal Mobile Telecommunication System; the 3rd generation mobile standard
VHO	Vertical Handover
VPN	Virtual Private Network - The use of encryption in the lower protocol layers to provide a secure connection through an otherwise insecure network, typically the Internet
WAP	Wireless Application Protocol – a set of protocols developed to deliver Data services to mobile phones, developed by WAP Forum.
W-CDMA	Wideband Code Division Multiple Access – a 3G mobile technology.
WLAN	Wireless LAN – LAN equipped with a wireless interface for use within corporations and for public hot-zone access to data services.

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Chapter 1

Introduction

1.1 Objectives

With the development of 4G mobile communication systems, more and more mobile hosts now a day are equipped with multiple network interfaces which are capable of connecting to the internet. As a result, an interesting problem surfaced on how to decide the "best" network to use at a "best" time moment.

The decision to decide best network may be based on static factors such as the bandwidth of each network (capacity), usage charges of each network, power consumption of each network interface and battery level of mobile device. However, Dynamic factors must be considered in handoff decisions for effective network usage. For example, information on current network conditions such as received signal strength(RSS) can help in improving whole system performance; current user conditions, such as a mobile host's moving speed can eliminate certain networks from consideration(i.e. those networks that do not support mobility).

Hence, in this major project, our objective is to develop and implement a *dynamic decision model* which helps in taking the right vertical handoff decisions by determining the "best" network at "best" time among available networks, based on dynamic factors such as "Received Signal Strength (RSS)" of network and "velocity" of mobile station as well as static factors. This model not only meets the individual user needs but also improve the whole system performance by reducing the unnecessary handoffs.

1.2 Background

The Heterogeneous networks are expected to become a main focus in the development toward the next generation wireless networks. Mobility management is a main challenge in the heterogeneous network. It addresses two main problems: *location management and handoff management*.

Location management tracks the Mobile Terminals (MT) for successful information delivery. Handoff management maintains the active connections for roaming mobile terminals as they change their point of attachment to the network. Handoff management is the main concern of this project.

In the heterogeneous or converged network [16], both intra-technology handoff and inter-technology handoff take place as illustrated in Figure 1.1. Intra-technology handoff is the traditional Horizontal Handoff (HHO) process in which the mobile terminal hands-off between two Access Points (AP) or two Base Stations (BS) using the same access technology. On the other hand, inter-technology handoff, or Vertical Handoff (VHO), occurs when the MT roams between different access technologies.

The main distinction between VHO and HHO is symmetry. While HHO is a symmetric process, VHO is an asymmetric process in which the MT moves between two different networks with different characteristics. This introduces the concept of a *Preferred Network,* which is the network that provides better throughput performance at lower cost, even if several other networks are available and in good condition for the user.

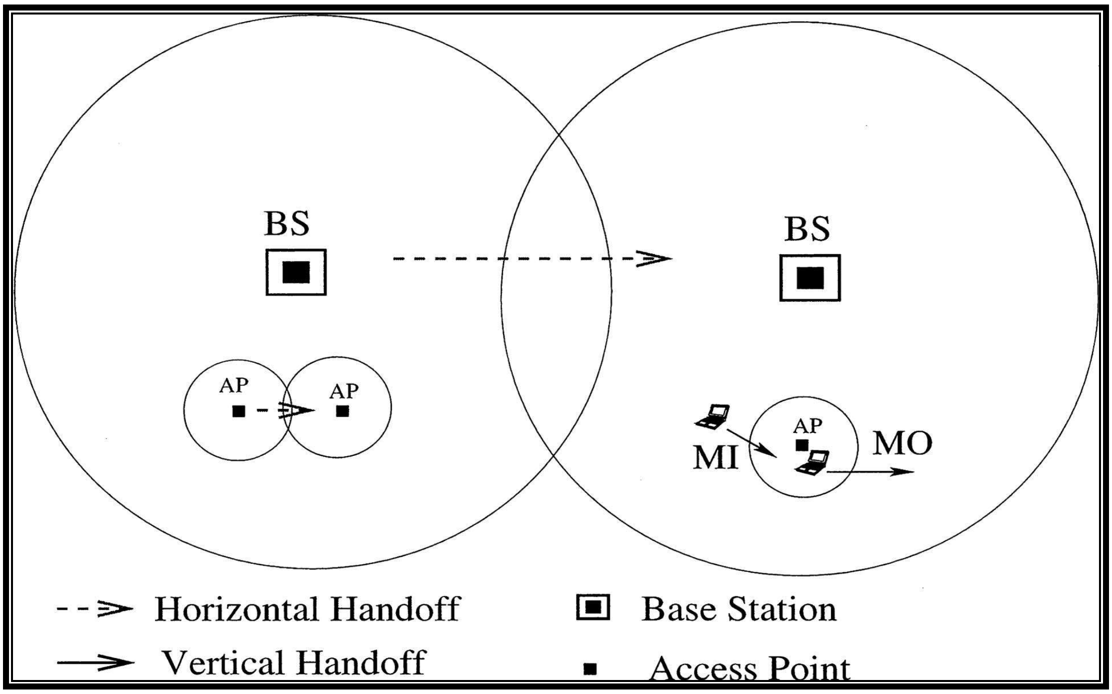


Figure 1.1: Horizontal and Vertical Handoff

There are two main scenarios in VHO: *moving out of the preferred network (MO) and moving into the preferred network (MI)*. In the converged model, it is highly desirable to associate the MT with the preferred network, as long as the preferred network satisfies the user application and preferences. This can improve both, the resource utilization of access networks as well as the user perceived quality of service (QoS). Furthermore, this handoff should be *seamless* with minimum user intervention, while dynamically adapting to the wireless channel state, network layer characteristics, and application requirements.

A *seamless handoff* is defined as a handoff scheme that maintains the connectivity of all applications on the mobile device when the handoff occurs. Seamless handoffs aim to provide continuous end-to-end data service in the face of any link outages or handoff events.

Criterion of a vertical handoff is one of the chief challenges for seamless mobility. Traditional handoff detection operations and policies, decision metrics, radio link transfer and channel assignment are not able to acclimatize to dynamic vertical handoff conditions or varying network availabilities. Furthermore, traditional handoff does not allow for device selection of networks since it assumes that there is only one type of network. In a mixed networking environment, user choice is a desirable enhancement.

1.3 The Methodology

The process of developing a Dynamic Decision Model comprises of following stages:

- The work started with a detailed study on the past and present wireless networks, their service requirements and technology employed, followed by the study on the future wireless networks (4G Networks), their structures and technologies required.
- This is followed by a study on Handover with an emphasis on vertical handover process, decision factors and implementation techniques.
- Based on this a decision model is proposed and analysed to perform handoff decisions dynamically using RSS and "velocity of mobile terminal" as dynamic decision factors.
- Then an application is developed in VC++ to implement and simulate this model for a heterogeneous wireless network comprising WLAN, GSM and CDMA networks.
- The results thus obtained are analyzed and compared with the results of the standard decision model based on static parameters only, to check the effectiveness of the proposed decision model.

Chapter 2

Overview of Wireless Networks

Wireless networking refers to technology that can support voice and/or data network connectivity using wireless, via a radio transmission solution. The most familiar application of wireless networking is the mobile phone. In the past, wireless communications predominantly used circuit switching to carry voice over a network; however, more recently both voice and data are being transmitted over both circuit-switched and packet-switched networks. The radio spectrum allocated to mobile networks has expanded over time. Below is a summary of the generations of wireless networking.

2.1 Evolution from 1G to 4G

First Generation (1G)

The evolution of mobile service [2] from the 1G (first generation) to 4G (fourth generation) began with the designs in the 1970s that have become known as ***1G***. The 1G mobile systems were based on analogue transmission. They had a low traffic density of one call per radio channel, poor voice quality, and they used insecure and unencrypted transmission, which led to the spoofing of identities. The first 1G system was launched in 1981.

Second Generation (2G)

The ***2G (second generation)*** systems designed in the 1980s were still used mainly for voice applications but were based on digital technology, including digital signal processing techniques. These 2G systems provided circuit-switched data communication services at a low speed. The competitive rush to design and implement digital systems led to a variety of different and incompatible standards such as GSM mainly in Europe; CDMA and TDMA in the U.S.; PDC in Japan.

GSM launched in 1991 is the most popular standard in use today, using 900MHz and 1800MHz frequency bands. GSM mobile systems developed digital transmission using SIM (Subscriber Identity Module) technology to authenticate a user for identification and billing purposes, and to encrypt the data to prevent eavesdropping. The transmission uses TDMA (Time Division Multiple Access) and CDMAOne (Code Division Multiple Access One) techniques to increase the amount of information transported on the network. Mobility is supported at layer 2, which prohibits seamless roaming across heterogeneous access networks and routing domains. This means each operator must cover the whole area or have agreements in place to permit roaming.

Second to Third Generation Bridge (2.5G)

An interim step is being taken between 2G and 3G, the ***2.5G***. It is basically an enhancement of the two major 2G technologies to provide increased capacity on the 2G RF (radio frequency) channels and to introduce higher throughput for data service, up to 384 kbps. A very important aspect of 2.5G is that the data channels are optimized for packet data, which introduces access to the Internet from mobile devices, whether telephone, PDA (personal digital assistant), or laptop. An example 2.5G network is GPRS launched in 2000. GPRS (General Packet Radio Service) is a data service which enables mobile devices to send and receive e-mails and picture messages.

Third Generation (3G)

The 3***G (third generation)*** systems designed in the 1990s to eliminate previous incompatibilities and become a truly global system. The 3G systems have higher quality voice channels, as well as broadband data capabilities. The third generation of mobile systems unifies different mobile technology standards, and uses higher frequency bands for transmission and Code Division Multiple Access to deliver data rates of up to 2Mbit/s to support multimedia services (MMS: voice, video and data). The European standard is UMTS (Universal Mobile Telecommunication Systems). Mobile systems continue to use digital transmission with SIM authentication for billing systems and for data encryption.

Data transmission uses a WCDMA (Wideband Code Division Multiple Access) to achieve data rates between 384kbit/s and 2048kbit/s. Some 3G suppliers use ATM (Asynchronous Transfer Mode) for their ‘over the air’ network with MPLS (Multiprotocol Label Switching) or IP for their backbone network. Mobility is still supported at layer 2, and therefore like 2G it still prohibits seamless roaming across heterogeneous access networks and routing domains. The transmission band frequencies are between 1900 and 2200 MHz. The UMTS is first launched by UK in 2003.

Fourth Generation (4G)

However, the demand for, higher access speed, multimedia communication and “Any where, any Time” seamless computing in today's society leads the research towards a 4G mobile communication system. 4G is still at the research stage. It is based on an ad hoc networking model where there is no need for a fixed infrastructure operation. Ad hoc networking requires global mobility features and Seamless roaming. As mobile devices will not rely on a fixed infrastructure, they will require enhanced intelligence to self configure in ad hoc networks and have routing capabilities to route over a packet-switched network.

2.2 Fourth Generation (4G) Wireless Networks

The term 4G is used broadly to include several types of broadband wireless access communication systems including cellular telephone systems. One of the terms used to describe 4G is *MAGIC—Mobile multimedia, Anytime anywhere, Global mobility support, Integrated wireless solution, and Customized personal service.*

The 4G cellular broadband wireless access systems will have broader bandwidth, higher data rate, and smoother and quicker handoff and will focus on ensuring seamless service across a multitude of wireless systems and networks. Application adaptability and being highly dynamic are the main features of 4G services of interest to users. Figure 2.1 illustrates key features of 4G systems.

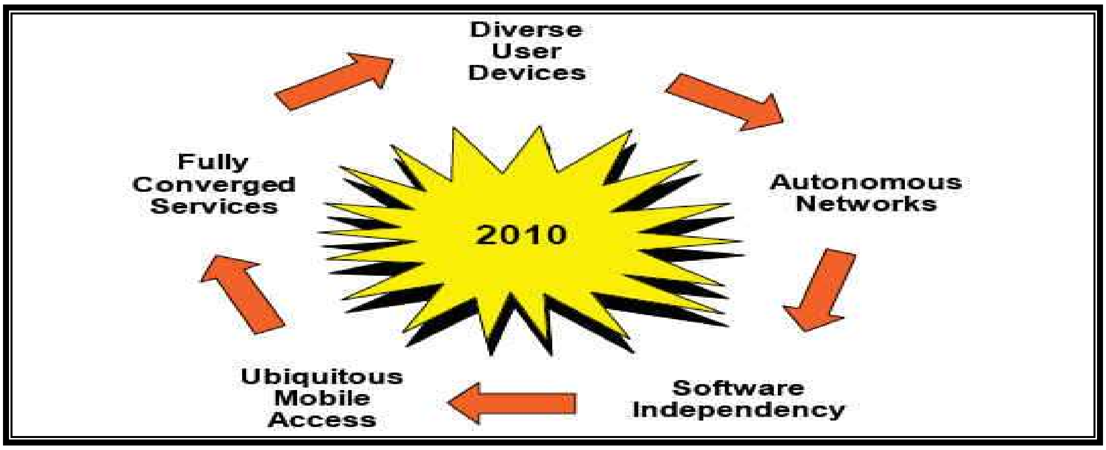


Figure 2.1: Key features of 4G Mobile systems

These features mean services can be delivered and be available to the personal preference of different users and support the users' traffic, air interfaces, radio environment, and quality of service. Connection with the network applications can be transferred into various forms and levels correctly and efficiently. The dominant methods of access to this pool of information will be the mobile telephone, PDA, and laptop to seamlessly access the voice communication, high-speed information services, and entertainment broadcast services. Figure 2.2 illustrate techniques to support the adaptability of the 4G.

The fourth generation will encompass all systems from various networks, public to private; operator-driven broadband networks to personal areas; and ad hoc networks. This all-encompassing integrated perspective shows the broad range of systems that the fourth generation intends to integrate, from satellite broadband to high altitude platform to cellular 3G and 3G systems to WLL (wireless local loop) and FWA (fixed wireless access) to WLAN (wireless local area network) and PAN (personal area network), all with IP as the integrating mechanism. Figures 2.3 demonstrate this seamless connectivity of the networks.

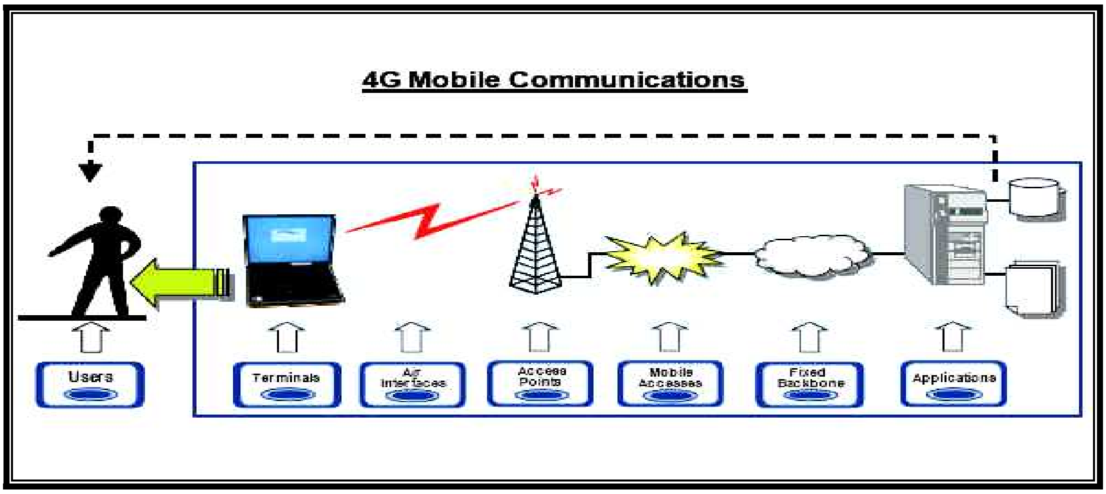


Figure 2.2: 4G Visions

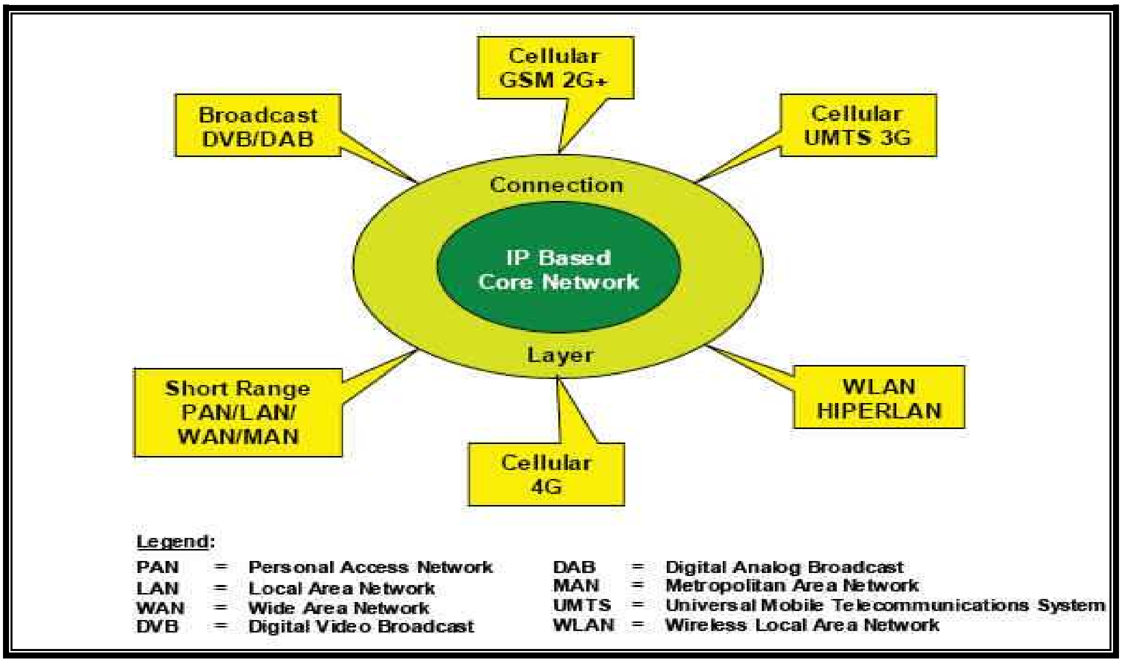
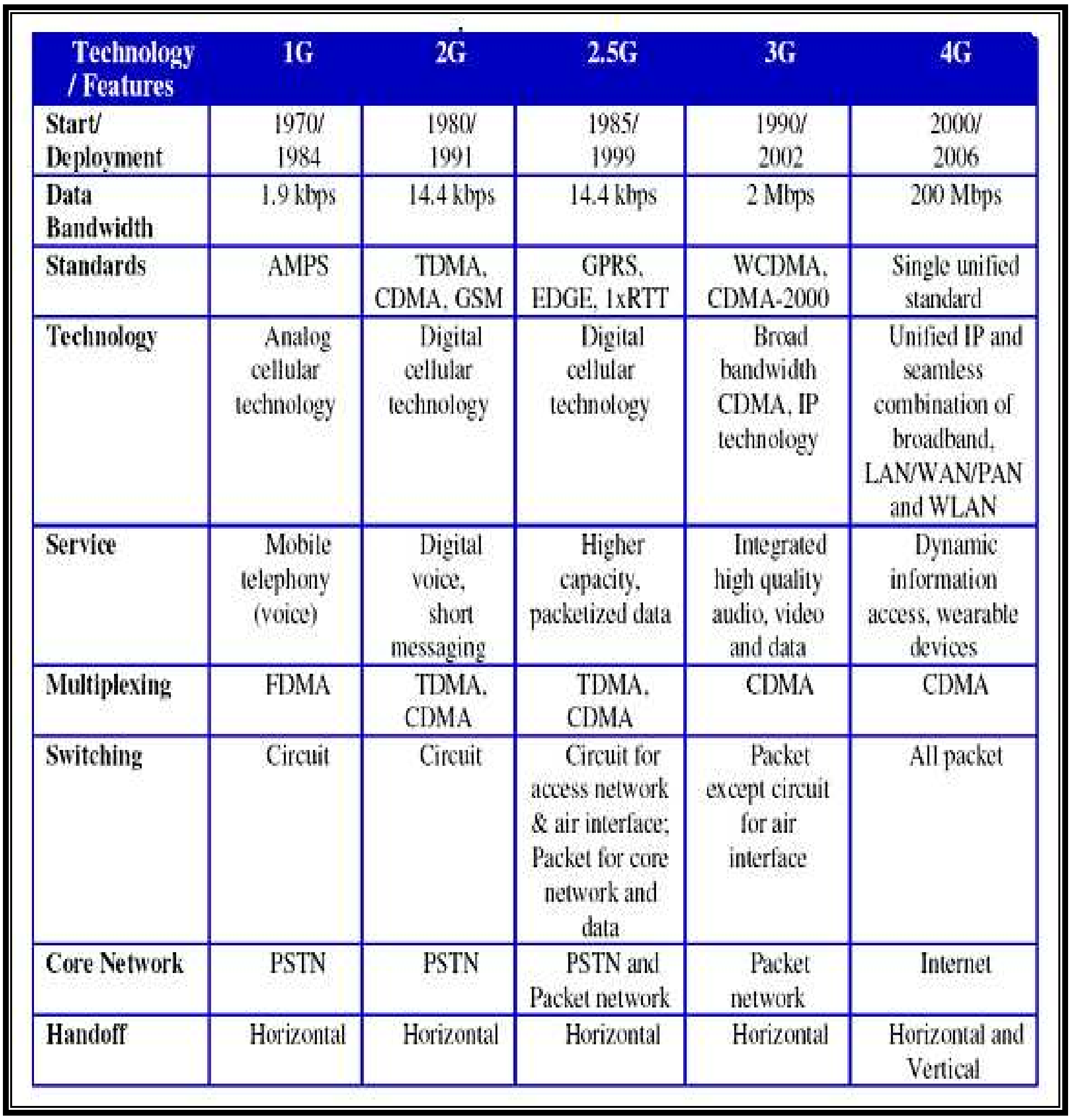


Figure 2.3: Seamless connections of networks

2.3 Comparison between 1G to 4G

The history and various features of wireless communication from 1G to 4G are summarised and compared in Table 2.1.

Table 2.1:Comparison of 1G-4G Technologies



Technology / Features	1G	2G	2.5G	3G	4G
Start/ Deployment	1970/ 1984	1980/ 1991	1985/ 1999	1990/ 2002	2000/ 2006
Data Bandwidth	1.9 kbps	14.4 kbps	14.4 kbps	2 Mbps	200 Mbps
Standards	AMPS	TDMA, CDMA, GSM	GPRS, EDGE, 1xRTT	WCDMA, CDMA-2000	Single unified standard
Technology	Analog cellular technology	Digital cellular technology	Digital cellular technology	Broad bandwidth CDMA, IP technology	Unified IP and seamless combination of broadband, LAN/WAN/PAN and WLAN
Service	Mobile telephony (voice)	Digital voice, short messaging	Higher capacity, packetized data	Integrated high quality audio, video and data	Dynamic information access, wearable devices
Multiplexing	FDMA	TDMA, CDMA	TDMA, CDMA	CDMA	CDMA
Switching	Circuit	Circuit	Circuit for access network & air interface; Packet for core network and data	Packet except circuit for air interface	All packet
Core Network	PSTN	PSTN	PSTN and Packet network	Packet network	Internet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal and Vertical

Legend:

1xRTT = 2.5G CDMA data service up to 384 kbps
AMPS = advanced mobile phone service
CDMA = code division multiple access
EDGE = enhanced data for global evolution
FDMA = frequency division multiple access
GPRS = general packet radio system

GSM = global system for mobile
NMT = Nordic mobile telephone
PDC = personal digital cellular
PSTN = pubic switched telephone network
TACS = total access communications system
TDMA = time division multiple access
WCDMA = wideband CDMA

2.4 Wireless Standards

2.4.1 GSM

Global System for Mobile communications (*GSM*: originally from *Groupe Special Mobile*) is the most popular standard for mobile phones in the world. Its ubiquity makes international roaming very common between mobile phone operators, enabling subscribers to use their phones in many parts of the world. GSM differs from its predecessors in that both signalling and speech channels are digital, and thus is considered a *second generation* (2G) mobile phone system. This has also meant that data communication was easy to build into the system.

The ubiquity of the GSM standard has been advantageous to both consumers (who benefit from the ability to roam and switch carriers without switching phones) and also to network operators (who can choose equipment from any of the many vendors implementing GSM). GSM also pioneered a low-cost alternative to voice calls, the *Short message service* (SMS, also called "text messaging"), which is now supported on other mobile standards as well.

GSM users can send and receive data, at rates up to 9600 bps, to users on POTS (Plain Old Telephone Service), ISDN, Packet Switched Public Data Networks, and Circuit Switched Public Data Networks using a variety of access methods and protocols, such as X.25 or X.32. Since GSM is a digital network, a modem is not required between the user and GSM network, although an audio modem is required inside the GSM network to interwork with POTS.

Architecture of the GSM network

A GSM network is composed of several functional entities, whose functions and interfaces are specified. Figure 2.4 shows the layout of a generic GSM network. The GSM network can be divided into three broad parts. The Mobile Station is carried by the subscriber. The Base Station Subsystem controls the radio link with the Mobile Station. The Network Subsystem, the main part of which is the Mobile services Switching Centre (MSC), performs the switching of calls between the mobile users, and between mobile and fixed network users. The MSC also handles the mobility management operations. Not shown is the Operations and Maintenance Centre, which oversees the proper operation and setup of the network. The Mobile Station and the Base Station Subsystem communicate across the Um interface, also known as the air interface or radio link. The Base Station Subsystem communicates with the Mobile services Switching Centre across the A interface.

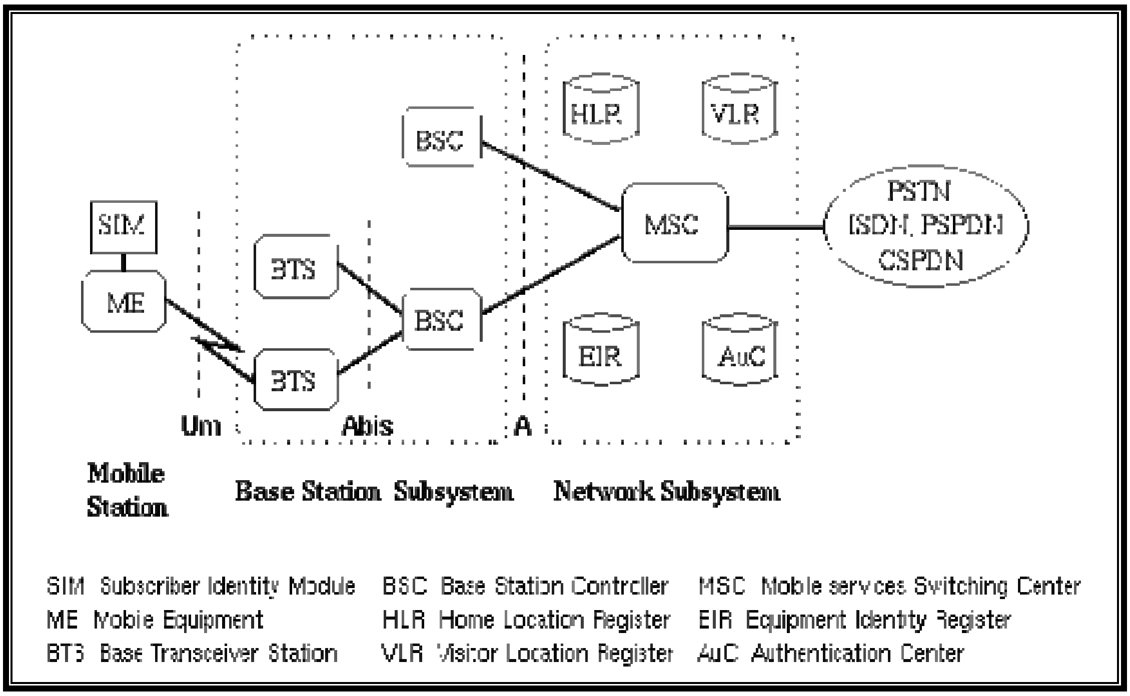


Figure 2.4: General architecture of a GSM network

The mobile station (MS) consists of the mobile equipment (the terminal) and a smart card called the Subscriber Identity Module (SIM). The SIM provides personal mobility, so that the user can have access to subscribed services irrespective of a specific terminal. By inserting the SIM card into another GSM terminal, the user is able to receive calls at that terminal, make calls from that terminal, and receive other subscribed services. The mobile equipment is uniquely identified by the International Mobile Equipment Identity (IMEI). The SIM card contains the International Mobile Subscriber Identity (IMSI) used to identify the subscriber to the system, a secret key for authentication, and other information. The IMEI and the IMSI are independent, thereby allowing personal mobility. The SIM card may be protected against unauthorized use by a password or personal identity number. The *Home Location Register (HLR)* and *Visitor Location Register (VLR)*, together with the MSC, provide the call-routing and roaming capabilities of GSM.

The *HLR* contains all the administrative information of each subscriber registered in the corresponding GSM network, along with the current location of the mobile. The location of the mobile is typically in the form of the signalling address of the VLR associated with the mobile station. There is logically one HLR per GSM network, although it may be implemented as a distributed database.

The *VLR* contains selected administrative information from the HLR, necessary for call control and provision of the subscribed services, for each mobile currently located in the geographical area controlled by the VLR.

The other two registers are used for authentication and security purposes. The *Equipment Identity Register (EIR)* is a database that contains a list of all valid mobile equipment on the network, where each mobile station is identified by its *International Mobile Equipment Identity (IMEI)*. An IMEI is marked as invalid if it has been reported stolen or is not type approved. The Authentication Centre (AuC) is a protected database that stores a copy of the secret key stored in each subscriber's SIM card, which is used for authentication and encryption over the radio channel.

The International Telecommunication Union (ITU), which manages the international allocation of radio spectrum (among many other functions), allocated the bands 890-915 MHz for the uplink (mobile station to base station) and 935-960 MHz for the downlink (base station to mobile station) for mobile networks in Europe.

The multiplexing method used by GSM to allocate the limited bandwidth among multiple users is a combination of Time- and Frequency-Division Multiple Access (TDMA/FDMA). The FDMA part involves the division by frequency of the (maximum) 25 MHz bandwidth into 124 carrier frequencies spaced 200 kHz apart. One or more carrier frequencies are assigned to each base station. Each of these carrier frequencies is then divided in time, using a TDMA scheme. The fundamental unit of time in this TDMA scheme is called a *burst period* and it lasts 15/26 ms (or approx. 0.577 ms). Eight burst periods are grouped into a *TDMA frame* (120/26 ms, or approx. 4.615 ms), which forms the basic unit for the definition of logical channels. One physical channel is one burst period per TDMA frame.
Channels are defined by the number and position of their corresponding burst periods. All these definitions are cyclic, and the entire pattern repeats approximately every 3 hours. Channels can be divided into *dedicated channels*, which are allocated to a mobile station, and *common channels*, which are used by mobile stations in idle mode.

Handover in GSM

In a cellular network, the radio and fixed links required are not permanently allocated for the duration of a call. There are four different types of handover in the GSM system, which involve transferring a call between:

- Channels (time slots) in the same cell
- Cells (Base Transceiver Stations) under the control of the same Base Station Controller (BSC),

- Cells under the control of different BSCs, but belonging to the same Mobile services Switching Centre (MSC), and
- Cells under the control of different MSCs.

The first two types of handover, called I*nternal Handovers*, involve only one Base Station Controller (BSC). To save signalling bandwidth, they are managed by the BSC without involving the Mobile services Switching Centre (MSC), except to notify it at the completion of the handover. The last two types of handover, called E*xternal Handovers*, are handled by the MSCs involved. An important aspect of GSM is that the original MSC, the *anchor MSC*, remains responsible for most call-related functions, with the exception of subsequent inter-BSC handovers under the control of the new MSC, called the *relay MSC*. Handovers can be initiated by either the mobile or the MSC (as a means of traffic load balancing). During its idle time slots, the mobile scans the Broadcast Control Channel of up to 16 neighbouring cells, and forms a list of the six best candidates for possible handover, based on the received signal strength. This information is passed to the BSC and MSC, at least once per second, and is used by the handover algorithm.

2.4.2 CDMA

*Code Division Multiple Access (CDMA***)** is a radically new concept in wireless communications. It has gained widespread international acceptance by cellular radio system operators as an upgrade that will dramatically increase both their system capacity and the service quality.

CDMA is a form of spread-spectrum, a family of digital communication techniques that have been used in military applications for many years. The core principle of spread spectrum is the use of noise-like carrier waves, and, as the name implies, bandwidths much wider than that required for simple point-to-point communication at the same data rate. Originally there were two motivations: either to resist enemy efforts to jam the communications (anti-jam, or AJ), or to hide the fact that communication was even taking place, sometimes called low probability of intercept (LPI).

CDMA changes the nature of the subscriber station from a predominately analog device to a predominately digital device. Old-fashioned radio receivers separate stations or channels by filtering in the frequency domain. CDMA receivers do not eliminate analog processing entirely, but they separate communication channels by means of a pseudo-random modulation that is applied and removed in the digital domain, not on the basis of frequency. Multiple users occupy the same frequency band. This universal frequency reuse is not fortuitous. On the contrary, it is crucial to the very high spectral efficiency that is the hallmark of CDMA. CDMA is altering the face of cellular and PCS communication by:

- Dramatically improving the telephone traffic capacity
- Dramatically improving the voice quality and eliminating the audible effects of multipath fading
- Reducing the incidence of dropped calls due to handoff failures
- Providing reliable transport mechanism for data communications, such as facsimile and internet traffic
- Reducing the number of sites needed to support any given amount of traffic
- Simplifying site selection
- Reducing deployment and operating costs because fewer cell sites are needed
- Reducing average transmitted power
- Reducing interference to other electronic devices
- Reducing potential health risks

Commercially introduced in 1995, CDMA quickly became one of the world's fastest-growing wireless technologies. In 1999, the International Telecommunications Union selected CDMA as the industry standard for new "third-generation" (3G) wireless systems. Many leading wireless carriers are now building or upgrading to 3G CDMA networks in order to provide more capacity for voice traffic, along with high-speed data capabilities.

Access Schemes

For radio systems there are two resources, frequency and time. Division by frequency, so that each pair of communicators is allocated part of the spectrum for all of the time, results in Frequency Division Multiple Access (FDMA). Division by time, so that each pair of communicators is allocated all (or at least a large part) of the spectrum for part of the time results in Time Division Multiple Access (TDMA). In Code Division Multiple Access (CDMA), every communicator will be allocated the entire spectrum all of the time. CDMA uses codes to identify connections.

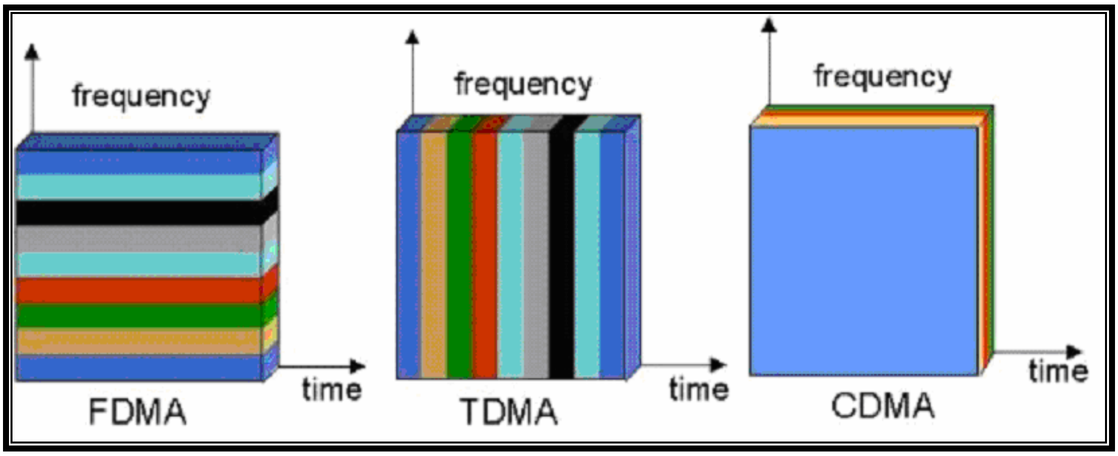


Figure 2.5: Multiple Access Schemes

Codes

CDMA codes are not required to provide call security, but create a uniqueness to enable call identification. Codes should not correlate to other codes or time shifted version of itself. Spreading codes are noise like pseudo-random codes, channel codes are designed for maximum separation from each other and cell identification codes are balanced not to correlate to other codes of itself.

CDMA Spreading

CDMA is a form of Direct Sequence Spread Spectrum communications. In general, Spread Spectrum communications is distinguished by three key elements:

1. The signal occupies a bandwidth much greater than that which is necessary to send the information. This results in many benefits, such as immunity to interference and jamming and multi-user access.
2. The bandwidth is spread by means of a code which is independent of the data. The independence of the code distinguishes this from standard modulation schemes in which the data modulation will always spread the spectrum somewhat.
3. The receiver synchronizes to the code to recover the data. The use of an independent code and synchronous reception allows multiple users to access the same frequency band at the same time.

In order to protect the signal, the code used is pseudo-random. It appears random, but is actually deterministic, so that the receiver can reconstruct the code for synchronous detection. This pseudo-random code is also called pseudo-noise (PN). CDMA uses unique spreading codes to spread the baseband data before transmission. The signal is transmitted in a channel, which is below noise level. The receiver then uses a correlator to despread the wanted signal, which is passed through a narrow bandpass filter. Unwanted signals will not be despread and will not pass through the filter. Codes take the form of a carefully designed one/zero sequence produced at a much higher rate than that of the baseband data. The rate of a spreading code is referred to as chip rate rather than bit rate.

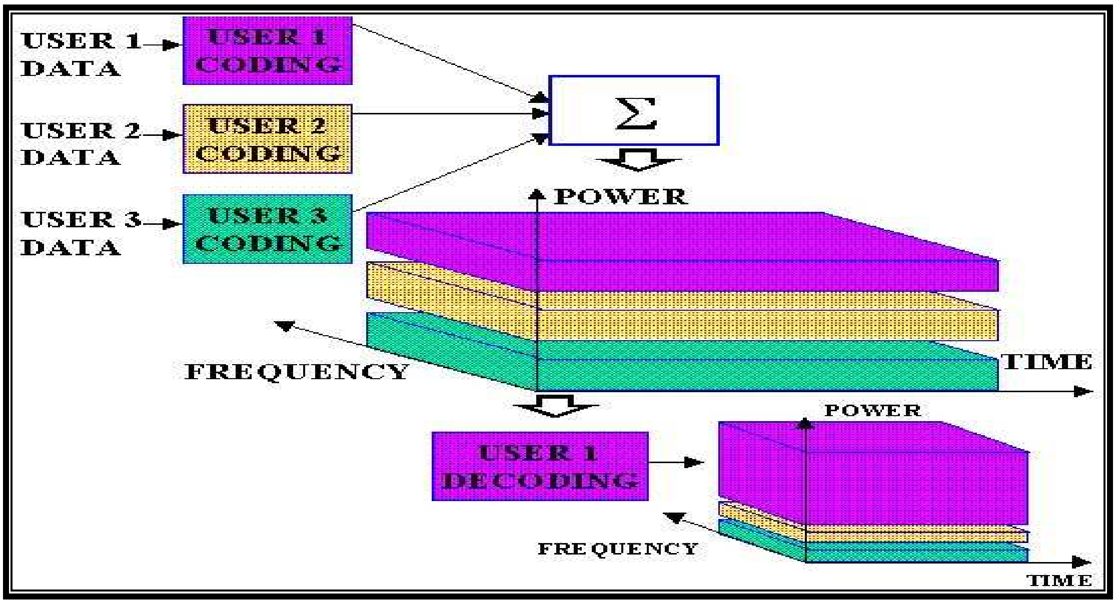


Figure 2.6: CDMA spreading

Handover

Handover occurs when a call has to be passed from one cell to another as the user moves between cells. Since all cells in CDMA use the same frequency, it is possible to make the connection to the new cell before leaving the current cell. This is known as a "make-before-break" or "soft" handover. Soft handovers require less power, which reduces interference and increases capacity. Mobile Terminal (MT) can be connected to more that two Base Terminal Stations (BTS) before the handover. "Softer" handover is a special case of soft handover where the radio links that are added and removed belong to the same Node B.

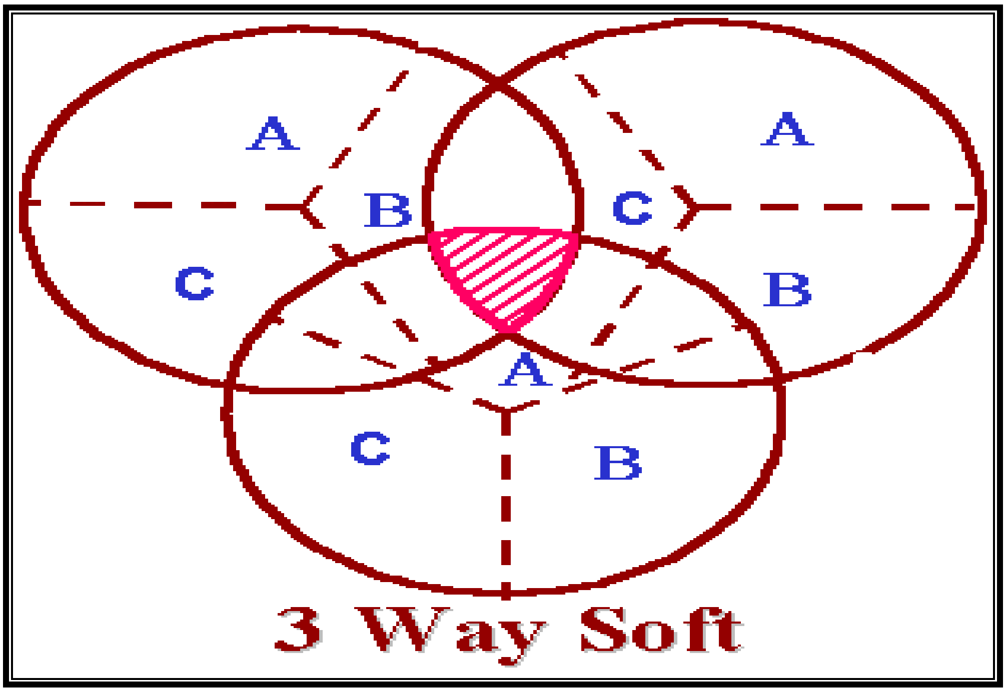


Figure 2.7 CDMA soft handover

2.4.3 WLAN

Wireless local area networks (WLAN) provides a high bandwidth service over a narrow geographic area and are typically restricted in their diameter to buildings, a campus or single rooms. There are two types of WLANs: *infrastructure and ad-hoc.*

Infrastructure networks often provide access to other networks such as Internet. Communication typically only takes place between the wireless nodes and an *access point (AP)*. The stations and the access point that are within the same radio coverage form a *basic service set (BSS*). Several BSS may form one logical wireless network called *extended service set (ESS)* and is identified by a name (ESSID). So it is possible to reach Internet through a WLAN with a wireless node where the node is located within the radio coverage for the WLAN. An overview of an infrastructure WLAN (IEEE 802.11) that is bridged to the Internet is shown in figure 2.8.

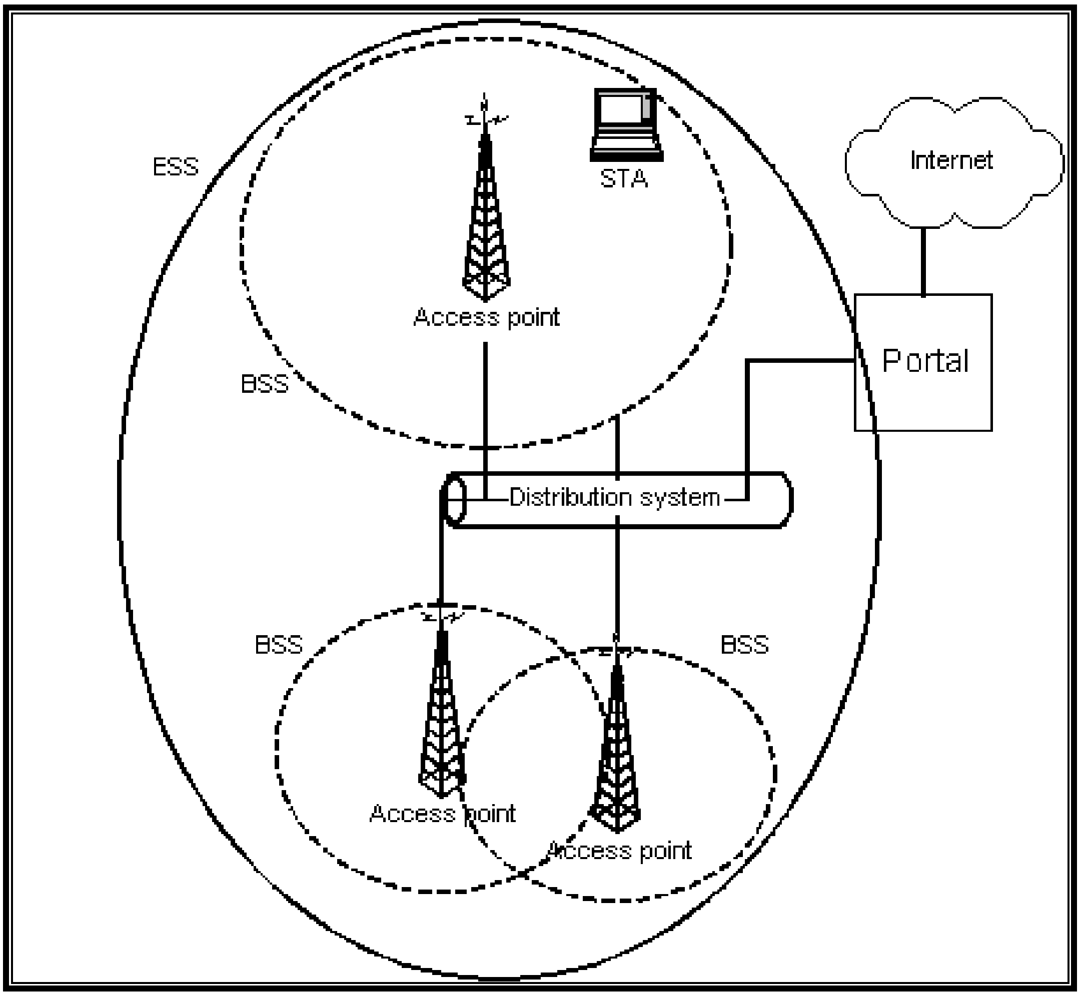


Figure 2.8: Wireless LAN (IEEE 802.11) overview

Ad-hoc networks don't need any infrastructure to work. Each wireless node can communicate directly with other nodes, so no access points are needed. The complexity of each node in an ad-hoc network is much higher than in an infrastructure. The IEEE 802.11 standard defines the physical and medium access control (MAC) layer. The 802.11link layer is transparent to the IP layer together with upper part of the link layer called logical link control (LLC). The LLC layer provides an interface to the IP layer and covers the differences of the medium access control layers needed for the different media. Figure 2.9 shows the protocol architecture from a wireless node via an access point to a wired node.

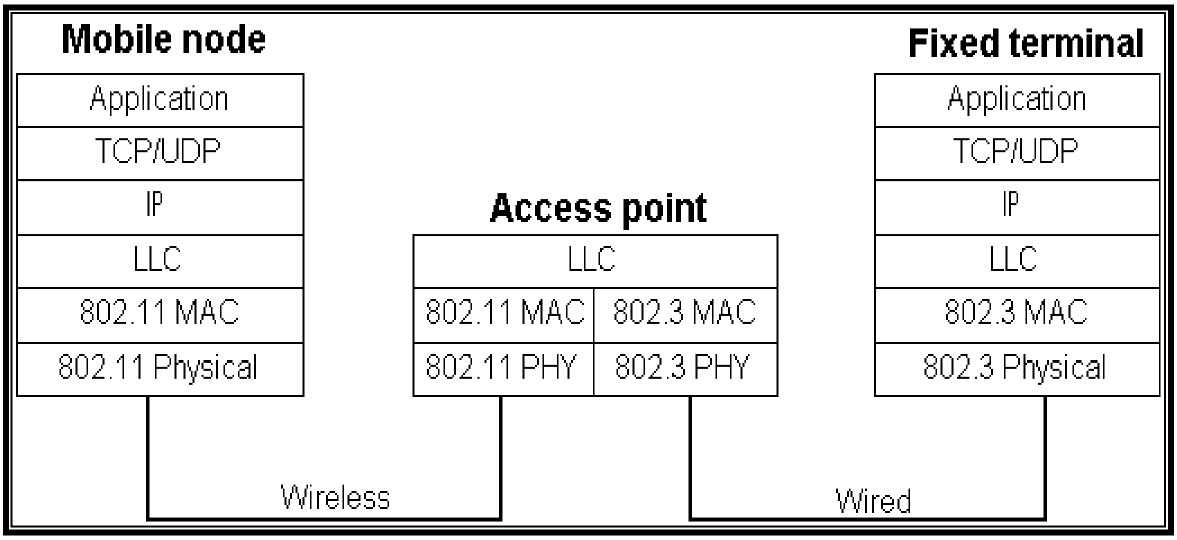


Figure 2.9: Protocol architecture

The IEEE standard 802.11 specifies the most common family of WLANs. However, some more advanced WLAN standards have also been developed. Table 2.2 below briefly presents the features of various WLAN Standards.

Table 2.2: WLAN STANDARDS

STANDARD	DATA RATE	MODULATION SCHEME	SECURITY	PROS/CONS & MORE INFO
IEEE 802.11	Up to 2Mbps in the 2.4GHz band	FHSS or DSSS	WEP & WPA	This specification has been extended into 802.11b.
IEEE 802.11a (**Wi-Fi**)	Up to 54Mbps in the 5GHz band	OFDM	WEP & WPA	Eight available channels. Less potential for RF interference than 802.11b and 802.11g.
IEEE 802.11b (**Wi-Fi**)	Up to 11Mbps in the 2.4GHz band	DSSS with CCK	WEP & WPA	Not interoperable with 802.11a. Requires fewer access points than 802.11a for coverage of large areas. Offers high-speed access to data at up to 300 feet from base station. 14 channels available in the 2.4GHz band
IEEE 802.11g (**Wi-Fi**)	Up to 54Mbps in the 2.4GHz band	OFDM above 20Mbps, DSSS with CCK below 20Mbps	WEP & WPA	May replace 802.11b. Improved security enhancements over 802.11. Compatible with 802.11b. 14 channels available in the 2.4GHz band
IEEE 802.16 (WiMAX)	Specifies WiMAX in the 10 to 66 GHz range	OFDM	DES3 and AES	Commonly referred to as WiMAX or less commonly as Wireless MAN. IEEE 802.16 is a specification for fixed broadband wireless metropolitan access networks (MANs)
IEEE **802.16**a (WiMAX)	Added support for the 2 to 11 GHz range.	OFDM	DES3 and AES	Commonly referred to as WiMAX or less commonly as Wireless MAN. IEEE 802.16 is a specification for fixed broadband wireless metropolitan access networks (MANs)
Bluetooth	Up to 2Mbps in the 2.45GHz band	FHSS	PPTP, SSL or VPN	No native support for IP, so it does not support TCP/IP and wireless LAN applications well. Not originally created to support wireless LANs. Best suited for connecting PDAs, cell phones and PCs in short intervals.

Chapter 3

Handover

This chapter introduces general concepts about handover. These concepts are useful in order to understand heterogeneous networks structure and handover between heterogeneous networks, as proposed in this thesis.

3.1 Heterogeneous Wireless Networks – An Overlay Structure

In the convergence of heterogeneous access networks, internet-working is aimed to provide mobile users with ubiquitous connectivity when moving across different networks. The integration of these different technologies requires the design of intelligent handover mechanisms and location management algorithms to enable continuity in services offered to users. In order to gain access to different access technologies, the mobile device should support multiple wireless network interfaces. The scenario described in this thesis, for the convergence of heterogeneous networks, is similar to the architecture for the so called "Wireless Overlay Networks", presented in [3]. This architecture consists on building-size, metropolitan and regional data networks and is shown in Figure 3.1

Wireless overlay networks are composed of a hierarchical structure consisting on overlapping cells with its own characteristics in terms of coverage, capacity, bandwidth, latency, and technology. In general, higher levels in the hierarchy provide lower bandwidths and higher delays over larger coverage areas. It can be seen that service areas are overlapped; an example could be the satellite link covering a group of small cities and serving as an umbrella for UMTS covering a cell in a city. The area covered by the WLAN is also covered by the UMTS and satellite technologies.

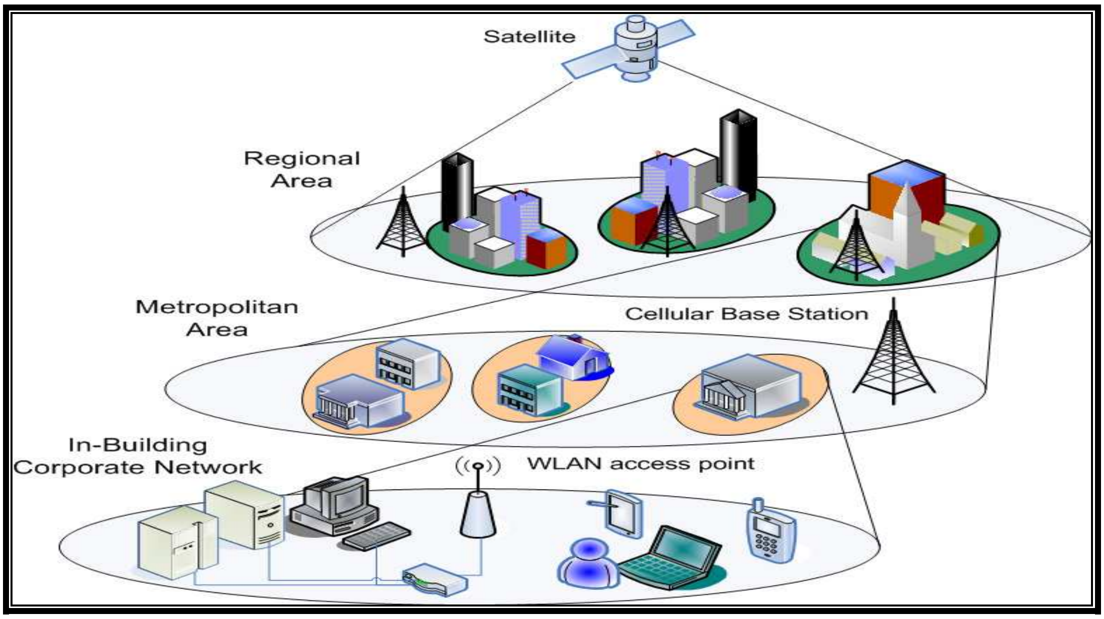


Figure 3.1: Overlay Wireless Networks

Having more than one access technology available, the selection of the network to be connected to, can be done according to different criteria and therefore the mechanism to switch between access technologies must be provided. Figure 3.2, shows existent heterogeneous wireless networks standards and its overlapping nature in terms of coverage. The convergence increases the coverage of the network and therefore the connectivity. In order to understand the requirements and considerations for a seamless handover the following sections describe some basic concepts.

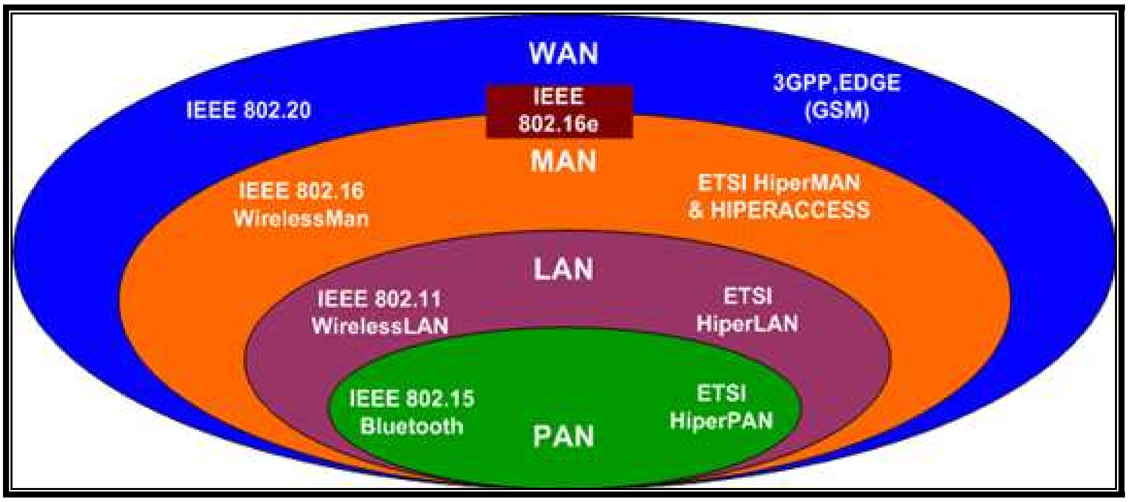


Figure 3.2: Coverage comparison of Overlay Wireless Networks

3.2 Handover in Heterogeneous Networks

Based on the architecture shown in Figure 3.1, handover can be seen from different points of view. Understanding these different perspectives is the base to select the mechanisms for the proposed SIP-supported handover.

3.2.1 Hard-Handover and Soft-Handover

A hard-handover happens when the mobile node being connected to an access point, with an ongoing session, loses connectivity due to the change of access point, after that, a new connection is established. Since communication is lost for a short period, this introduces a service interruption from the user point of view.

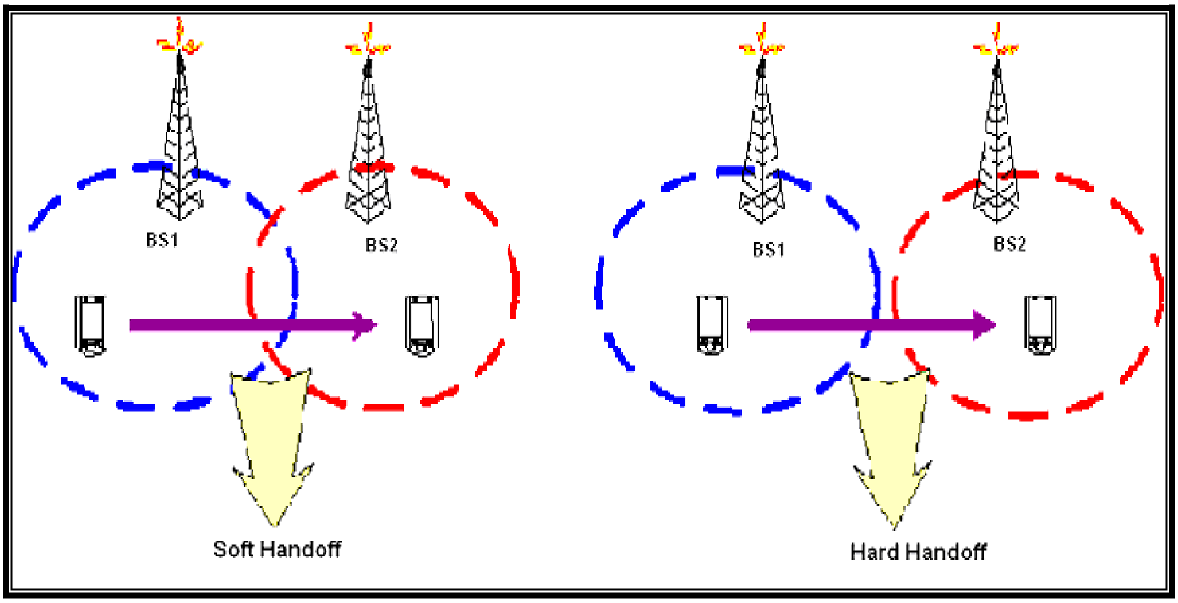


Figure 3.3: Soft and Hard Handoff

Soft-handover allows the mobile node being connected to multiple access points in different networks. When the handover happens the connection is created in the target access point before the old access point releases the connection, making the process transparent for the user.

3.2.2 Anticipated and unanticipated handover

Anticipated handover is the one that the mobile node will always want to perform. Unanticipated handover on the other hand does not include the preferences of the mobile node.

3.2.3 Horizontal and Vertical Handover

A handover performed when a user moves from one cell to another using the same access technology is called *horizontal or homogeneous handover*; a typical example could be a user moving between two cells in a cellular system. A handover performed when a user moves between different access technologies is called *vertical or heterogeneous handover*. Figure 3.4, shows both cases. The study in this thesis is referred to the implementation of a decision model for vertical handover.

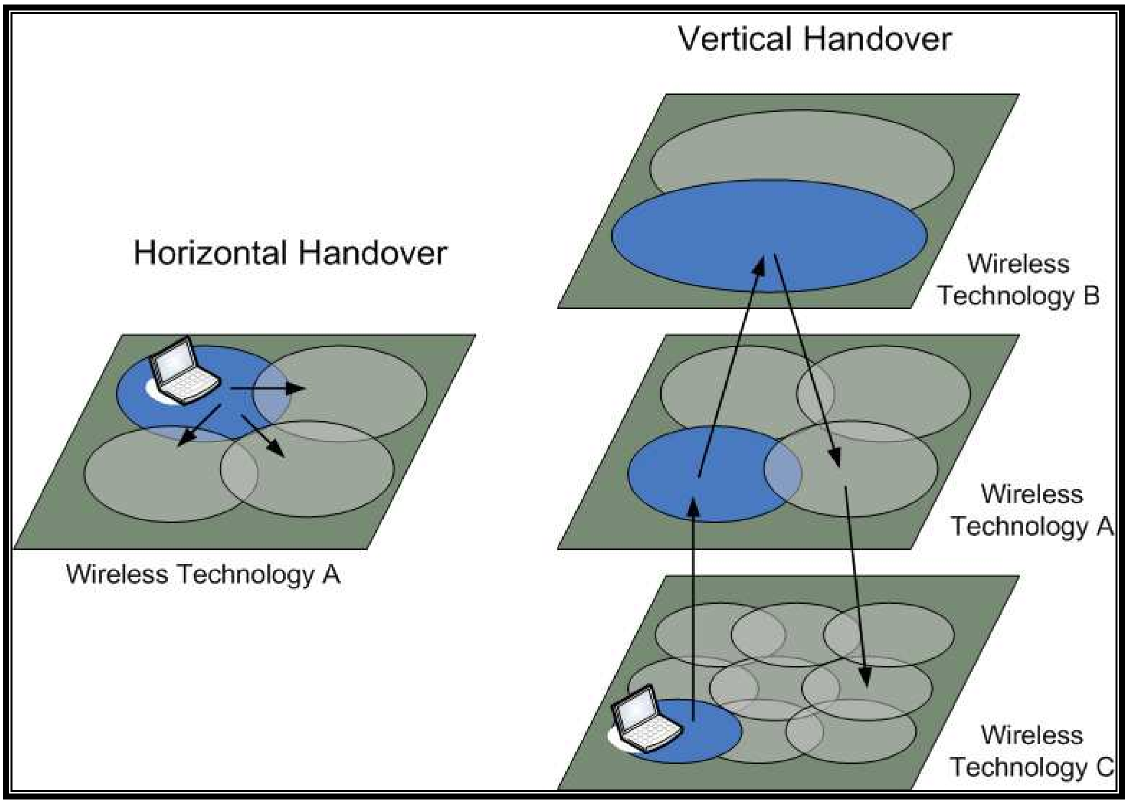


Figure 3.4: Handover between heterogeneous networks

3.2.3 Upward-vertical handover and Downward-vertical handover

If the cell size and available bandwidth are considered, the handover performed in heterogeneous networks when a user moves from a network with larger cell size and usually lower bandwidth to a network with lower cell size and usually higher bandwidth is called Downward-vertical handover, and example could be a user moving from WLAN to PAN. On the other hand, the handover that is performed to a network with higher cell size and generally lower bandwidth is called Upward vertical handover.

3.3 Vertical Handover Decision Characteristics

One of the chief issues that aid in providing seamless handoff is the ability to correctly decide whether or not to carryout vertical handoff at any given time. This could be accomplished by taking into consideration two key issues: *network conditions and connection maintenance*. To attain positive vertical handoff, the network state ought to be constantly obtainable by means of a suitable handoff metric. In multi-network environments, this is very challenging and hard to achieve as there does not exist a single factor than can provide a clear idea of when to handoff. Some of the most important decision factors are:

Cost of Service: The cost of the different services to the user is a major issue, and could sometimes be the decisive factor in the choice of a network. Different broadband Wireless Internet Service Providers (WISPs) and cellular service providers may well provide a variety of billing plans and options that will probably influence the customer's choice of network and thus handoff decision.

Power Requirements: Wireless devices operate on limited battery power. When the level decreases, handing off (or remaining connected) to a network with low power consumption can provide elongated usage time. For instance, if a device's battery is nearly exhausted then handing over from a WLAN to WWAN would be a smart decision. This is due to the fact that when operating in a cellular WWAN, the device is idle for most of the time.

Proactive Handoff: by proactive handoff, the users are involved in the vertical handoff decision and have the final decision on whether or not to handoff, regardless of the network conditions. By permitting the user to choose a preferred network the system is able to accommodate the user's special requirements.

Quality of Service (QoS): Handing over to a network with better conditions and higher performance would usually provide improved service levels. Transmission rates, error rates, and other characteristics can be measured in order to decide which network can provide a higher assurance of continuous connectivity.

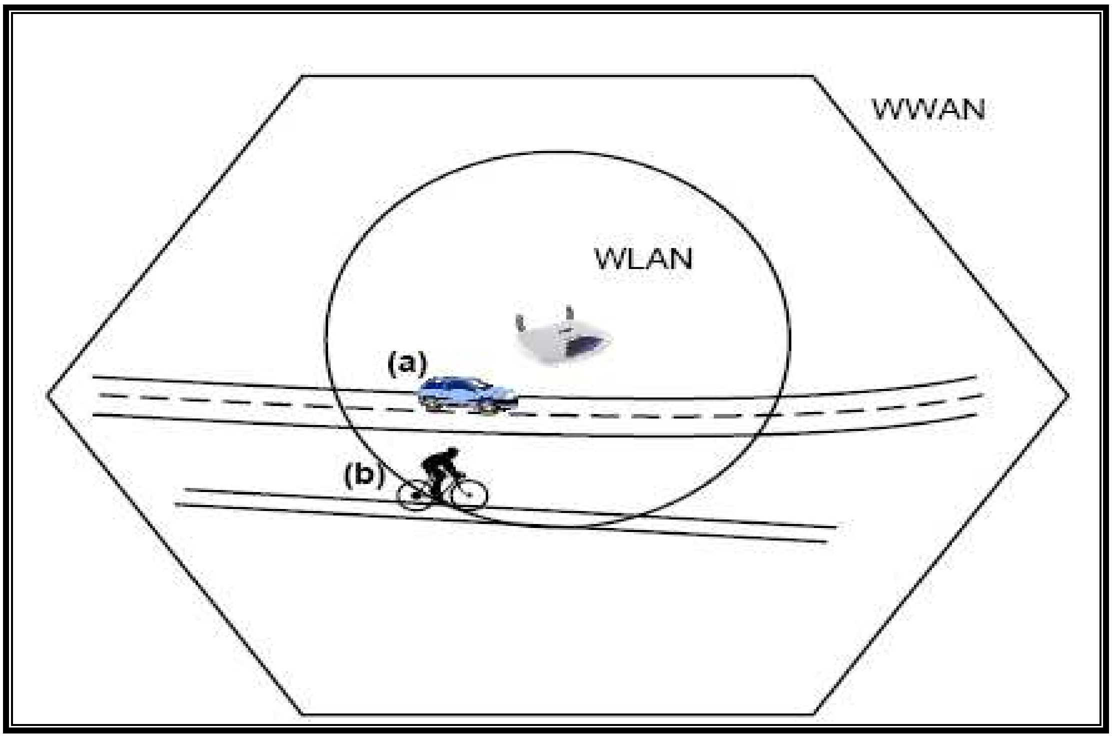


Figure 3.5: **Effects of (a) velocity and (b) location of mobile terminal on handoff**

Velocity: In vertical handoff, the velocity factor has a larger weight and imperative effect in handoff decision than in traditional horizontal handoffs. Because of the overlaid architecture of heterogeneous networks, handing off to an embedded network when travelling at high speeds is discouraged since a handoff back to the original network would occur very shortly afterwards. As shown in Figure 3.5(a) If a user's velocity is high, there is no need for handoff, even if the signal strength is very strong, since the user is mostly likely to leave after a short period of time.

Signal Strength: The signal strength has a great role in the Horizontal Handover (HHO) decisions due to its comparability with other cells. But In VHO, the RSSs are incomparable due to VHO's asymmetrical nature. However, they can be used to determine the availability as well as the condition of different networks**.** We have utilized it in the vertical handover to find out the comparative location of mobile terminal with respect to the Base station (BS) or Access Point (AP). This is done by calculating the difference between the received signal strength and its threshold value where less difference means less nearer to BS/AP. As shown in figure 3.5(b) although the cyclist's velocity is low, he is moving on the edge of the coverage and therefore handoff to the WLAN is discouraged. *As per my best knowledge, this is the first such use of signal strength in vertical handover solutions.*

Vertical handoff decisions cannot be based on one or a couple of the factors discussed. The majority of these aspects have a momentous effect on the correct network choice. In the proposed Dynamic Decision Model, above mentioned characteristics are taken into consideration with special emphasis on velocity and RSS in order to offer dynamic vertical handoff decisions across heterogeneous networks.

3.4 Vertical Handover process

Since the problem addressed in this thesis is the handover for the convergence of heterogeneous networks, defined as vertical handover, the process is explained in this section with some detail according to [4]. The process can be divided into three steps:

3.4.1 Network Discovery

In this initial step, the mobile node searches available wireless networks by listening service advertisements broadcasted by different technologies. In order to make this step feasible, it is assumed that the mobile node has multiple interfaces.

3.4.2 Handover decision

Once the available networks are discovered, the next step is to decide, if possible, whether or not to perform the handover. Due to the differences between access technologies, the decision can be driven by many factors such as described above in section 3.3.

3.4.3 Handover Implementation

The implementation of handover considers the packet's transference of the ongoing session to the new wireless link; this requires the network to transfer routing information about the new target router to establish a new session. Owing to differences between access technologies, transfer of additional contextual information might be required. This contextual information could include Quality of Service, authentication and authorization, among others. The aim of contextual transference is to minimize the impact of different access technologies and their polices to transfer different types of data on applications and services

Chapter 4

Implementation Approaches for Vertical Handover

4.1 Network Layer Approaches

4.1.1 Mobile IP

Mobile IP [5] is an Internet protocol for allowing transparent routing of IP datagram's to mobile nodes in Internet. If you want to reach a mobile node wherever it is located it has to have a static home IP address. That is achieved with mobile IP. When a mobile node moves and attaches itself to another network, it obtains a new IP address. This is necessary as the IP routing mechanism rely on the topological information embedded in the IP address to deliver the data to the correct end-point. Mobile IP handles this by network agents. No modifications on the routers or end hosts are required. Each mobile node is identified by a static home network address from its home network, regardless of its current point of attachment.

Terminology

- **Mobile node (MN):** A mobile node with a static IP address. The mobile node can change its point of attachment to the Internet using mobile IP.
- **Correspondent node (CN):** Mobile nodes communication partner. The correspondent node can be fixed or a mobile node.
- **Home network**: The subnet the mobile nodes home IP address is belonging to.
- **Foreign network**: The current subnet the mobile node is visiting.
- **Home Agent (HA):** Is located in the home network. The home agent can be implemented on the router at the home network or

at a regular node in the home network. The home agent can work as manager for the mobile node. With the manager solution the mobile node is always in a foreign network. When a mobile node is outside the home network the home agent receives all packets destined to the mobile node and tunnels them to the current location of the mobile node.

- **Foreign Agent (FA):** The foreign agent provides services to the mobile node during its visit to the foreign network. The foreign agent acts as the tunnel end-point, decapsulates incoming packets and forwards them to the mobile node. The foreign agent is typically implemented on the router at the foreign network. A foreign agent is not necessary needed; if the foreign agent is discarded the mobile node has to decapsulates the incoming packets itself. The mobile node is then co-located.
- **Care-of address (COA):** The care-of address defines the current IP address of the mobile node. All packets sent to the mobile node are sent to the home agent and tunnelled to the care-of address. The care-of address is the tunnel endpoint. The care-of address can be located at two different points, at the foreign agent or at the mobile node directly. If the care-of address is located at the mobile node directly, the mobile node is then co-located.
- **Tunnel:** The path followed by a datagram while it is encapsulated. The model is that, while it is encapsulated, a datagram is routed to a knowledgeable decapsulating agent, which decapsulates the datagram and then correctly deliver it to its ultimate destination.

While a mobile node is away from its home network, it updates the home agent with information about its current IP address. The home agent receives all incoming packets destined to the mobile node, encapsulates and tunnels them to the mobile nodes current IP address (COA). When the mobile node wants to send packets to the correspondent node two options is available. The simpler way is to send the IP packet to the correspondent node with the mobile nodes home address as source address instead of the care-of address. But there are some problems with this option; many intranets only allow packets with topologically correct addresses to pass. Since the source address of the IP packet is changed, the address will not be topologically correct. The other alternative is to use reverse tunnelling, when the mobile node wants to send a packet to the correspondent node it encapsulate and tunnels the packet to the home agent. The home agent then decapsulates the packet and forwards it to the correspondent node as when a packet is sent from the correspondent node to the mobile node. This is called R*everse Tunnelling*. Figure 4.1 shows the scenario when the mobile node is located in a foreign network and communicates via a foreign agent. The home agent and the foreign agent are acting as tunnel endpoints.

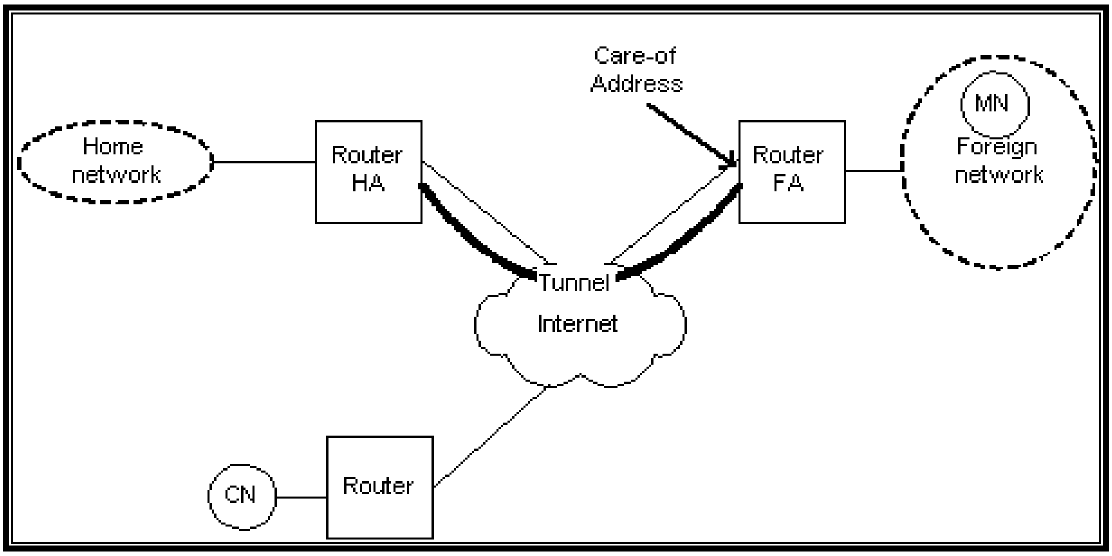


Figure 4.1: Mobile IP overview

When the mobile node is outside its home network it has to try to find a foreign network. Finding a foreign agent is done in two ways; either the agent sends out agent advertisement messages or the mobile node is sending out agent solicitation messages. The home and foreign agents advertise their presence by sending out advertisement messages periodically. A mobile node in a wireless subnet can receive an advertisement message either from a home or a foreign network. If a mobile node wants to find a wireless subnet but are not receiving any advertisement messages it can send out solicitations messages. An agent responds to a solicitation message and the mobile node can receive a care-of address. When a mobile node has found a subnet, either the home or a foreign network, it has to register at the agent. If the mobile node is in a foreign network the registration can be done in two ways, through a foreign agent or directly to the home agent. If the mobile node is using a foreign agent the registration goes through the foreign agent. The mobile node sends a registration request containing the care-of address to the foreign agent, which forwards the request to the home agent. The home agent sets up tunnel from the home agent to the foreign agent. The registration expires after negotiated lifetime; this is for avoiding mobility bindings which are no longer used. The home agent sends a reply message to the mobile node through the foreign agent after setting up the tunnel. If the mobile node not is using a foreign agent the registration message is sent directly to the home agent. All registration packets are sent using UDP as transport protocol. Figure 4.2 shows both register cases.

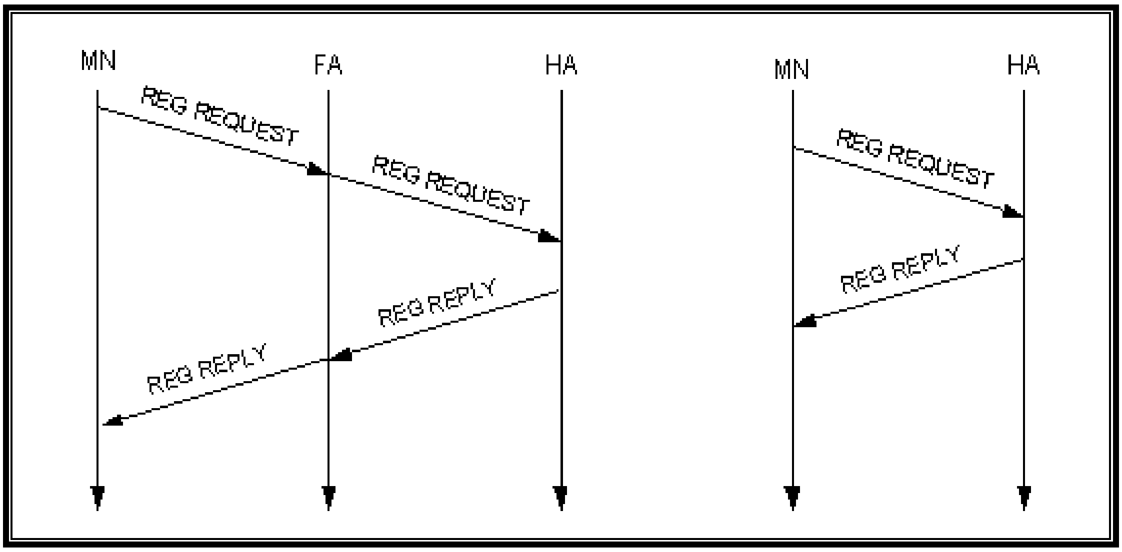


Figure 4.2: Registration of a mobile node

4.1.2 Mobility support in IPv6

IPv6 is a new version of IP and is intended to replace the current version IPv4 as Internet protocol. The length of the address has been increased from 32 bits to 128 bits. In mobile IPv6 [6] as in mobile IPv4 each mobile node is always identified by its home address, regardless of its current point of attachment to the Internet.

When the mobile node is away from the home network the mobile node is associated with a care-of address (COA). Each time the mobile nodes move from one subnet to another, the node will configure its COA with another COA belonging to the new subnet. The configuration can be done with DHCPv6 or PPPv6. Mobile IPv6 enables any IPv6 node to learn and cache the COA for a mobile node. This is for avoiding T*riangular Routing* and to packet is sent using an IPv6 routing header instead of IPv6 encapsulation. A mobile node's association to a COA is known as binding and has a remaining lifetime. This is for other nodes to know how long to store the COA in the binding cache. When sending an IPv6 packet to any destination, a node checks its binding cache for an entry for the packet's destination address. If an address is found in the cache the packet is sent directly to the COA instead through a home agent where it has to get encapsulated. Mobile IPv6 introduces a set of new messages to achieve this, *Binding Update* and *Binding Acknowledgement.* After a mobile node has configured its COA, it must send a *Binding Update* to the HA and all corresponding nodes. The Binding Message contains the current COA for the mobile node. The recipient's updates their binding cache and sends a *Binding Acknowledgement* if so was requested in the *Binding Update* message. The *Binding Update* message can be sent separate or together with any payload such TCP or UDP. Although messages can be sent directly to the care-of address from a correspondent node to avoid triangular routing, the mobile node can always be reached through its home address. So the movement of the mobile node is thus transparent to the transport and higher layers protocols.

4.2 Transport Layer Approaches

Today most applications are communicating with either TCP or UDP as transport protocol. Introducing a new transport protocol to solve the seamless vertical handover problem has its disadvantages. Unfortunately almost all today's existing applications have to be rewritten to support a new transport protocol. Two proposals for a new transport layer protocol are considered, Stream Control Transmission Protocol (SCTP) [7] and TCP Multi Homing (TCP MH) [9].

4.2.1 Stream control transmission Protocol (SCTP)

Stream Control Transmission Protocol (SCTP) [7] offers a reliable delivery service for application over an IP network and is session-oriented. The most interesting feature of SCTP is multi-homing. An SCTP session can be established over multiple IP addresses. SCTP sends packets to a primary IP address, but can reroute packets to an alternative, secondary IP address if the primary IP address becomes unreachable. A SCTP session has a primary path between two SCTP hosts, but can also have multiple paths between the hosts. This type of session is defined as an association in SCTP. An SCTP association between two hosts A and B is defined as:

{[IP addresses of A] + [port A]} + {[IP addresses of B] + [port B]}

In the base version of SCTP the endpoints exchange their IP addresses before the SCTP association is established and these addresses cannot be changed during the session. However mobile SCTP (mSCTP) [8] supports adding, deleting or changing IP addresses during an active session using Address Configuration (ASCONF) messages. SCTP supports the end-to-end principle [10]; anything that can be done in the end system should be done there. Since the transport layer is the lowest end-to-end layer in the Internet protocol stack, the vertical handover should be done there [10]. The end-to-end principle says that anything that can be done in the end system should be done there [10]. Figure 4.3 shows the protocol stack with mSCTP as transport protocol. The mSCTP is transparent to the IP layer. In figure 4.4 a message procedure is shown. The Mobile node communicates to the correspondent node through the WLAN interface. The mobile node sends an ASCONF message and adds a GPRS IP address. Later the mobile node performs a handover and sends a ASCONF message which switches the primary IP address. Now all data to and from the mobile node are sent through the GPRS interface.

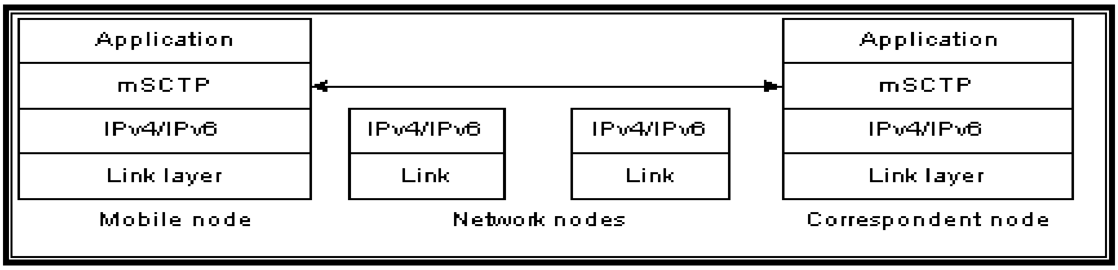


Figure 4.3: Protocol architecture

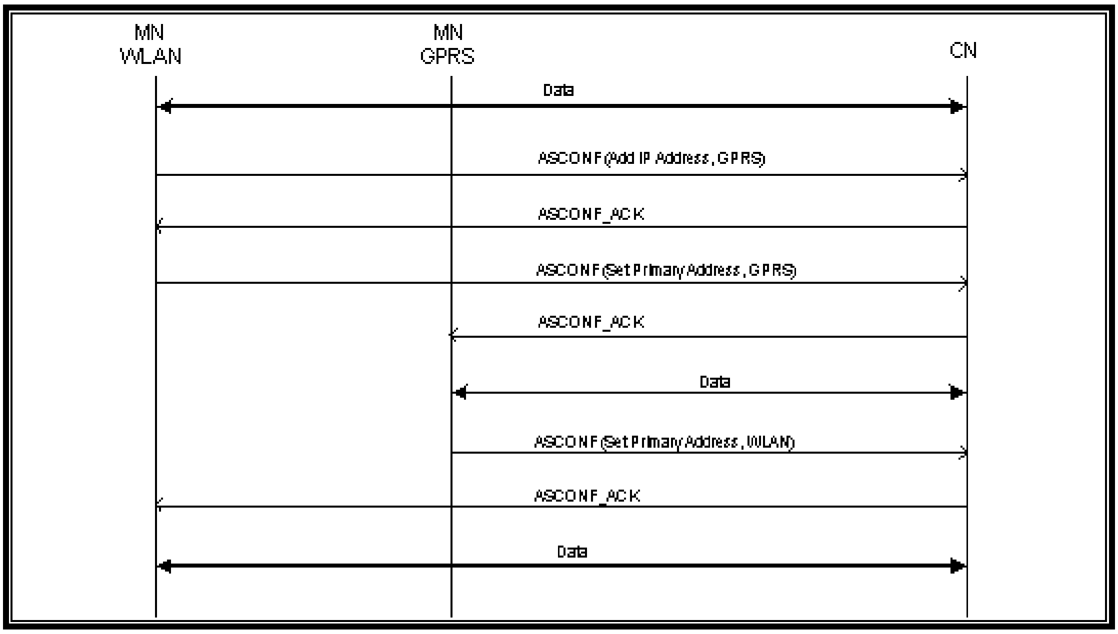


Figure 4.4: Vertical handover procedure with mSCTP

4.2.2 TCP Multi Homing (TCP-MH)

TCP Multi Homing (TCP-MH) [9] resembles SCTP but TCP-MH is just an extension of the existing TCP, not a complete new transport protocol. The existing TCP is only designed for communication between one local and one remote IP address. The TCP-MH option makes it possible to handle multiple local and remote addresses during a TCP session. TCP MH provides multi-home feature to TCP without modification and dependence on any other elements in the Internet. Features as flow control, slow start, collision avoidance and fast retransmission in TCP are kept in TCP-MH. A TCP-MH session starts with a MH-Permit option in a SYN packet. If host accepts MH-permit a SYN-ACK with MH-Permit packet is returned and MH options can be used. A TCP session can be kept even though the source and/or the destination address changes. A session can also switch from IPv4 address to IPv6 address and vice versa. Hosts exchange their IP addresses with MH-Add-IPv4 or MH-Add-IPv6 options. After an endpoint has received a MH-Add option the endpoint register the new transmission path. There are also MH-Delete options for deleting addresses. Figure 4.5 shows a mobile node trying to establish a connection from the WLAN interface, but no response returns from the correspondent node. Later the mobile node switches interface to the GPRS connection and tries to connect with that. The connection is established after an ACK from the correspondent node to the mobile node. The three- way handshake is finished after the correspondent node receives an ACK from the mobile node. When data is sent the mobile node uses the “MH-Add-IPv4” option, which tells the correspondent node that another IP address for the mobile node (IP for the WLAN interface) can be used. The correspondent node accepts that option and sends back an ACK. Later as seen in the picture the correspondent node sends data that doesn’t reach the mobile node and no ACK was received. The correspondent node then tries to send the data to the other IP address (WLAN) that is available for the session.

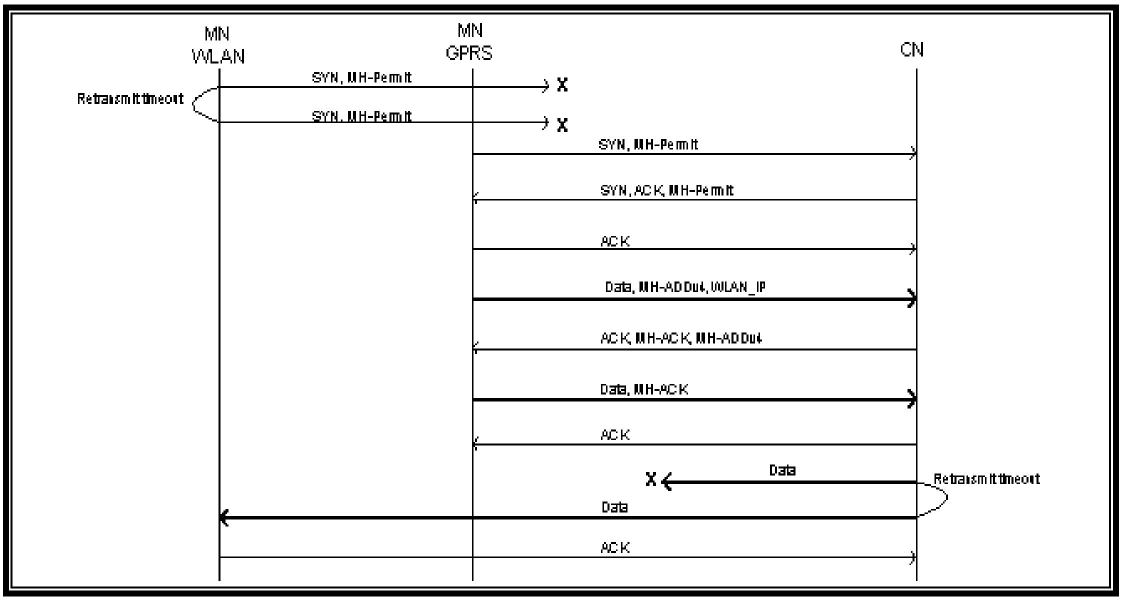


Figure 4.5: TCP-MH message overview

4.3 Upper Layer Approaches

These approaches implement a new session layer above the transport layer. The application sessions will be transparent to the connection changes in the underlying layers. A session layer can make a session exist between two applications instead of between two hosts. The session then has to be identified in another way than the IP numbers and port numbers. Some session ID has to identify a session between two applications.

4.3.1 Migrate approach

The Migrate approach [11] is a session-oriented end-to-end host mobility approach. The migrate approach propose a session layer. Sessions exists between application end points, and should survive changes in the transport and network layer protocol states. Once a session is established a locally unique token or Session ID identifies it. The authors of the migrate approach propose five important fundamental issues that has to be handled in Internet mobility.

1. *Locate the mobile host*: The desired end point must be located and mapped to an addressable destination.
2. *Preserving communication*: Once a session is established, communication should be able to handle changes in the network location of the end points.
3. *Disconnecting gracefully*: Disconnection should be rapidly detected.
4. *Hibernating efficiently*: If a host is unavailable for a period of time, the connection should be suspended and resources should be reallocated.
5. *Reconnecting quickly*: Communication peers should detect resumption of connectivity in timely manner. The system should be able to re-establish the connection without any extra effort.

Mobility support should be provided at the end hosts [10]. Many previous approaches like mobile IP rely on proxies. Proxy-based solutions have to deal with some performance issues. The proxies have to be well engineered and well located in the network to perform acceptably.

The selection of network end point and transport protocol remains under the application's control. Naming can abstract location details. The migrate approach provides a naming service; a mobile host isn't bound to a home IP address like in mobile IP. Instead the host is identified by a hostname. To locate mobile node hosts the widely deployed Domain Name System (DNS) is used. Many applications resolve hostnames to an IP address at the beginning of a connection. No home agent is necessary as in mobile IP. When a mobile node changes its location and IP address, it sends a DNS update to one of the name servers. Since the session is identified with a session ID the session can remain from the new location. The session layer has to re-synchronize the session between the hosts. The session layer has to handle and save the state of the connection to be able to continue the session after a reconnection from another IP address. It is possible to hijack the connection with this solution; a secure key exchange part has to be implemented in the session layer. The migrate approach uses the Elliptic Curve Diffie-Hellman for key exchanges. The same problem arises for the DNS update sent by the mobile node. The Migrate approach uses the security of dynamic DNS updates in RFC 2137. Figure 4.6 shows the components of the Migrate architecture. The session layer has four interfaces: session establishment, connectivity status, policy decisions and application up-calls.

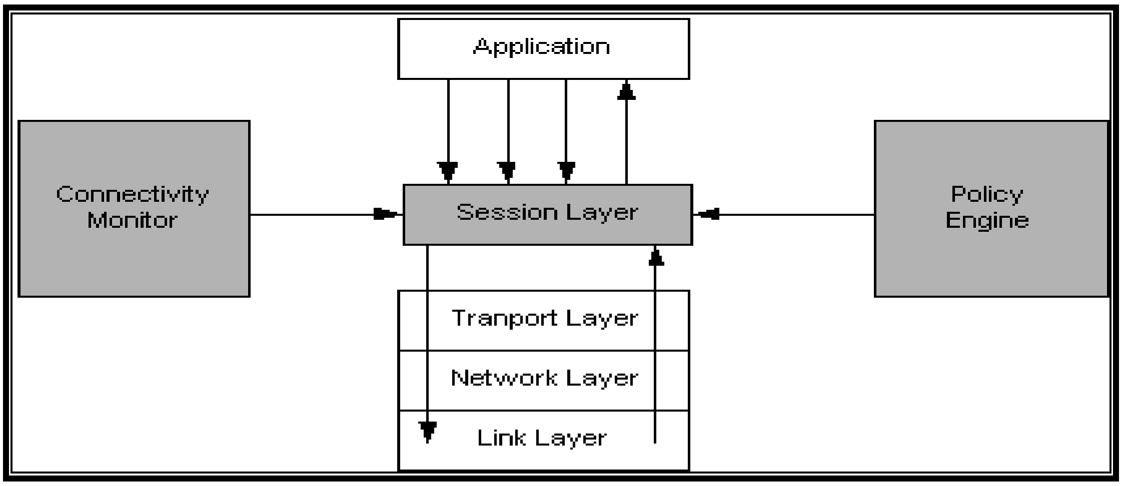


Figure 4.6: The Migrate session layer framework

4.3.2 MSOCKS

MSOCKS [12] is a proxy-based solution with a proxy inserted into the communication path between a mobile node and its correspondent host. MSOCKS is using a technique called TCP Splice. TCP Splice preserves the end-to-end semantics as normal TCP connection. Normally in proxy-based solutions each session between a mobile node and a correspondent node is split into two separate TCP connections. TCP Splice allows a machine where two independent TCP connections terminate to splice the two connections together. The connection will form a single end-to-end TCP connection between the endpoints of the two original connections with the proxy in the middle. The mobile node is communicating via a MSOCKS library that runs under the application. At the proxy a MSOCKS proxy process is running; an in-kernel modification on the proxy machine to provide the TCP Splice service. The correspondent host doesn't need any modifications. The MSOCKS protocol is built on top of the SOCKS protocol. The MSOCKS library has similar functions like bind, accept and connect as SOCKS does. An identifier identifies the session between mobile host and proxy. MSOCKS also has a reconnect function, when a mobile host wants to change network interface (IP-address) it opens a new connection to the proxy and sends a reconnect message with the session identifier. The proxy unsplices the old mobile-to-proxy connection and splices in the new mobile-to-proxy connection. The end-to-end semantics of TCP are maintained together with TCP Splice. TCP Splice makes it appear to the endpoints of two separate TCP connections that those two connections are, in fact, one. Data can be lost with this solution; ACK'd data to the correspondent host but lost in the transmission to the mobile host is lost forever.

MSOCKS library is a layer between the application and the transport layer. It provides an interface to the application while internally using the normal TCP stack. To get this to work the applications has to use this library instead of the existing SOCKS or the existing application has to be recompiled. Figure 4.7 shows a message exchange diagram when a MSOCKS client tries to connect to a server on a correspondent host. The MSOCKS library function *Mconnect*() is used for making this split connection. *Mconnect*() first makes a connection to the proxy then it sends the server's address and port number to the proxy in a Connect message. The proxy connects to the desired server and splices the mobile client-proxy and proxy-server connections together. When the splice is set up the proxy finally sends an OK message back to the mobile client.

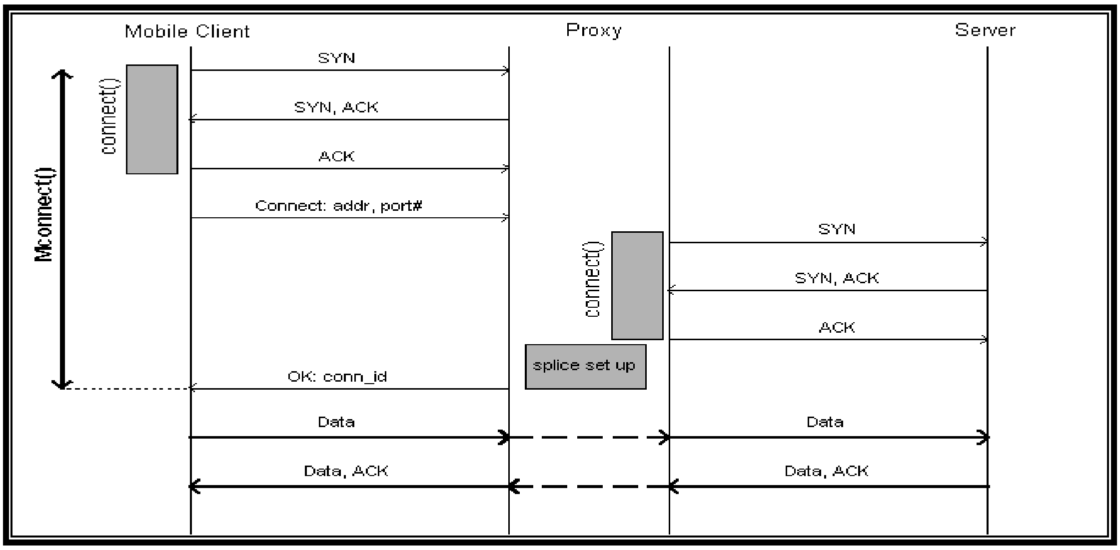


Figure 4.7: Message exchange diagram for connection establishment

4.3.3 Universal Seamless Handoff Architecture (USHA)

Universal seamless handoff architecture (USHA) [13] achieves seamless handoff by following the middleware design. The USHA doesn't require any infrastructure modification, but the solution assumes that handoff only occurs on overlaid networks. The USHA network is composed of a handoff server (HS) and several mobile hosts (MH). The HS and the MH are communicating using an IP tunnel. Each MH maintains a tunnel to the HS. All applications are communication using the tunnel interface instead of any physical IP addresses available. All packets communicating via the tunnel are encapsulated and transmitted to the HS using the UDP protocol. The tunnel has two virtual and two physical IP addresses. The applications are communicating using the virtual addresses and the tunnel is using the physical addresses to communicate. When a handoff occurs the physical IP address is switched on the mobile host. A handoff client is responsible for switching the physical address of the virtual tunnel to a new interface.

Chapter 5

Decision Approaches for Vertical Handover

The traditional HHO problem has been studied extensively in the past. Several approaches have been considered in cellular networks using the Received Signal Strength (RSS) as an indicator for service availability from a certain point of attachment. Additionally, several handoff initiation strategies have been defined based on the comparison between the current attachment point RSS and that of the candidate attachment points as shown in [16]:

- ***RSS*:** handoff takes place if the candidate attachment point RSS is higher than the current attachment point RSS ($RSSnew > RSScur$)
- ***RSS plus threshold*:** handoff takes place if the candidate attachment point RSS is higher than the current attachment point RSS and the current attachment point RSS is less than a pre-defined threshold T ($RSSnew > RSScur$ and $RSScur < T$).
- ***RSS plus hysteresis*:** handoff takes place if the candidate attachment point RSS is higher than the current attachment point RSS with a pre-defined hysteresis margin *H.* ($RSSnew > RSScur + H$)
- **A *dwell timer*** can be added to any of the above algorithms. In this case, the timer is started when one of the above conditions is satisfied, and the MT performs a handoff if the condition is satisfied for the entire dwell timer interval.

In VHO, the RSSs are incomparable due to VHO's asymmetrical nature. However, they can be used to determine the availability as well as the condition of different networks. If the MI decision is based only on the P*referred Network* availability, the MT should start the MI process as it discovers the preferred network. In addition, if more than one preferred network APs/BSs are available, the MT should associate itself with the one having the strongest RSS as it does in HHO. When the MT is associated with the preferred network, it enjoys all the preferred network advantages before moving out. Therefore, in the ideal MO scenario, the MT performs no more than one handoff at the *preferred network* edge when the network is expected to be unavailable. This ideal MO decision usually cannot be achieved. Thus, the main design requirements of a VHO algorithm are:

- minimizing the number of unnecessary handoffs to avoid overloading the network with signalling traffic,
- maximizing the underlay network utilization,
- providing active application with the required degree of QoS,
- prioritizing handoff to the underlay network over MO to the overlay network,
- avoiding MI to a congested network, and
- keeping fast users connected to the overlay network.

As far as we are aware, there exist very few works dealing with VHO beyond simple extensions to the common techniques for HHO. Three main approaches for VHO algorithms, recorded in the literature, are:

- The *first approach* is based on the traditional strategies of using the RSS that may be combined with other parameters such as network loading.
- The *second approach* uses artificial intelligence techniques combining several parameters such as network conditions and MT mobility in the handoff decision. However, these artificial intelligence based algorithms are complex and may be difficult to implement in practical systems.
- The *third approach* combines several metrics such as access cost, power consumption, and bandwidth in a cost function estimated for the available access networks, which is then used in the MT handoff decision.

Wang et al. introduce the policy enabled handoff in [17], which was followed by several papers on similar approaches. The authors proposes policies considering different parameters such as monetary cost, power consumption, network available bandwidth, and other parameters that differ among different heterogeneous networks. For each policy, a cost function is defined as a weighted sum of normalized policy parameters. These weights vary according to user preferences and the MT status (e.g., power reserve). In this scheme, the MT periodically compares the cost of different networks and then is handed off to the one with the minimum cost. Also, Chen et al. [15] introduce a smart decision model using a handoff control centre module in the MT. This module monitors the available interfaces and the system resources to collect information required for the handoff decision. This decision is based on a score function that considers the usage expenses, link capacity, and power consumption for the available access technologies. The MT uses the network that achieves the largest score. A decision strategy [18] considers the performance of the whole system while taking VHO decisions by meeting individual needs. This decision strategy select the best network based on the highest received signal strength (RSS) and lowest Variation of received signal strength (VRSS). It ensures the high system performance by reducing the unnecessary handoffs. A time adaptive VHO decision scheme [19] make right VHO decisions timely through adjusting interface activating intervals based on the user's movement and the actual network performance.

In *Dynamic Decision Model (DDM)* for VHO, we adopt the Third approach, of using the access cost, power consumption, and bandwidth in a cost function estimated for the available access networks, in association with RSS and MT "Velocity" combine as a unique inputs to the algorithm to eliminate the ineligible network and improving the overall system performance by reducing the No. of handoffs. In our best knowledge, this is first such effort of using received signal strength (RSS) with "velocity" of mobile terminal for reaching a vertical handover decisions.

Chapter 6

Proposed Dynamic Decision Model

We proposed a Dynamic decision model to support flexible configuration in executing vertical handoffs. Fig.6.1 depicts the proposed dynamic decision model. In the figure, a handoff management centre (HMC) monitors the various inputs collected from the various network interfaces and their base stations (BS), analyze this information and took decisions. It also provides the connection between the network interface and the upper layer applications. HMC is composed of five components: Network Analysis (NA), Network Discovery (ND), Dynamic Decision (ND), System Monitor(SM) and Handoff Manager & Executor (HME).

NA is responsible for monitoring the status of each network interface (i.e. offered bandwidth, user charges, power consumption of interface) and analyzing based on the calculated score function. SM monitors and reports system information (i.e. current remaining battery power and user preferences) to NA module. ND module discovers all the available networks at fixed time intervals. It monitors the velocity of mobile station (MS) and the Received signal strength (RSS) of the base station (BS) and took the decision regarding the candidate networks. Then the DD module achieves a dynamic decision based on the inputs from NA, SM and ND modules. Handoff Manager & Executor (HME) then performs the device handoff to the “Best” network selected if different from the current network.

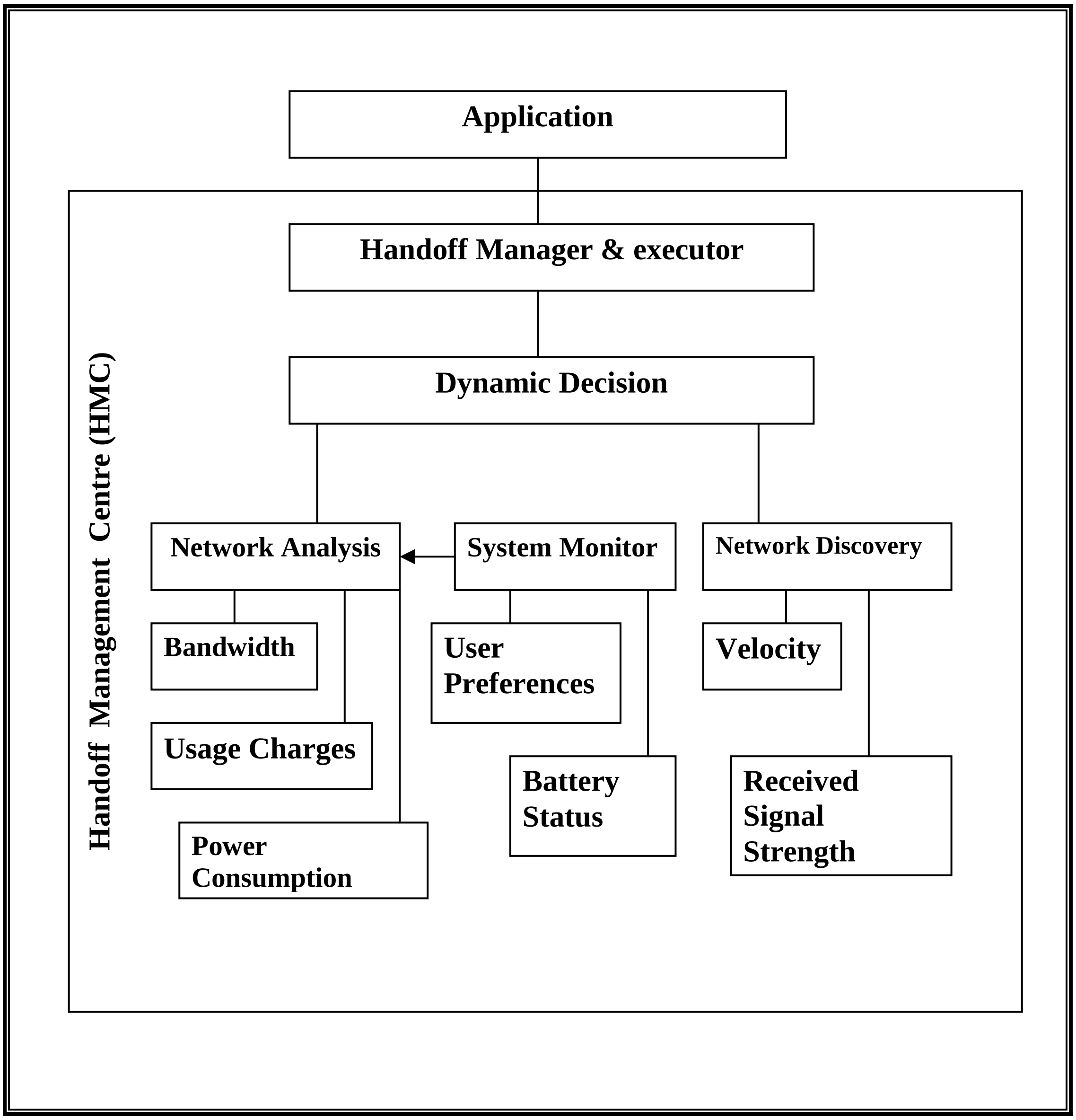


Fig. 6.1: Dynamic Decision Model

The algorithm for dynamic decision is described in figure 6.2. The *Priority Phase* is necessary to remove all the unwanted and ineligible networks from the prospective candidate networks. The *Normal Phase* is used to accommodate user-specific preferences regarding the usage of network interfaces. The user preferences are expressed in terms of weight factors. Finally, the *Decision Phase* is used to select the "Best" network and executing the handoff to the selected network.

Dynamic Decision Process

Priority Phase: (Network Discovery)

1. Add all the available network into candidate list
2. Scan all the networks and record their Received Signal Strength(RSS)
3. Record the velocity of the mobile station(MS)
4. Remove the networks which do not satisfy the required RSS and velocity criteria.
5. Calculate and assign the priorities to all the candidate networks based on the difference between RSS and its threshold value RSST.
6. Continue with Normal Phase

Normal Phase: (Network Analysis)

7. Collect current system status from SM component and determined the weight factors.
8. Collect information on every wireless interface in the candidate list.
9. Calculate static score “*S*’ using a *Cost function* for every network.
10. Continue with Decision Phase

Decision Phase: (Network Selection and Execution)

11. Calculate a dynamic *score “DScore”* by multiplying the *priority* of each candidate network with it’s static score “*S*”
12. Select the network with the highest value of “*DScore*”
13. Handoff all current information to the “Selected network” if different from current network.

Figure 6.2: Algorithm for Dynamic Decisions Process

6.1 System Monitor

This module is responsible to monitor the current battery level of the mobile station and record the user preferences for various networks based on the current battery level, offered bandwidth, usage charges and power consumption by their interfaces. These preferences are passed on to the Network Analysis module which converts them into the respective weight factors to calculate the score function.

6.2 Network Analysis

The analysis of the network is based on a score function S. the S can be defined as a function of the following parameters: the offered bandwidth (B_n), power consumption of using the network access device (P_n) and the usage charge of the network (C_n)-

$$S_n = f(B_n, P_n, C_n) \qquad (1)$$

We can imagine that such a score function is the sum of some normalized form of each parameter. Normalization is needed to ensure that the sum of the values in different units is meaningful.

In general, suppose that there are k factors to consider in calculating the score, the final score of the interface i will be a sum of k weighted functions.

$$S_i = \sum_{j=1}^{k} w_i f_{i,j} \quad 0 < S_i < 1, \qquad \sum_{j=1}^{k} w_j = 1 \qquad (2)$$

In the equation, w_j stands for the weight of factor j and $f_{i,j}$ represents the normalized score of interface i for factor j.

For our model –

$$S_i = w_b f_{b,i} + w_p f_{p,i} + w_c f_{c,i} \qquad (3)$$

Where

$f_{b,i} = e^{\alpha_i} / e^M \quad , \alpha_i \geq 0 \ \& \ M \geq \alpha_i$

(4)

$f_{p,i} = 1/e^{\beta_i} \quad , \beta_i \geq 0$ (5)

$f_{c,i} = 1/e^{\gamma_i} \quad , \gamma_i \geq 0$ (6)

The coefficients α_i, β_i, γ_i can be obtained via a lookup table or well-tuned functions as below:

$\alpha_i = \mathrm{Min}(x_i, M)/M \quad ; M = 2\mathrm{Mbps}$ (7)

$\beta_i = 2/y_i \quad ; y_i$: hours (8)

$\gamma_i = z_i / 20 \quad ; z_i$: Rs./min (9)

In Eq. 3, we used the inversed exponential equation for $f_{p,i}$ and $f_{c,i}$ to bound the result between zero and one (i.e. these functions are normalized), and properly model users preferences. For $f_{b,i}$, a new term *M* is introduced as the denominator to normalize the function, where *M* is defined as the maximum link capacity among all available interfaces. Note that, the properties of bandwidth and usage cost/power consumption are opposite (i.e. the more bandwidth the better, whereas lower cost/power consumption is preferred).

6.3 Network Discovery

The object of this module is to identify all the Candidate Networks from all the available networks and assign them Priority. A *candidate network* is the network whose received signal strength is higher than its threshold value and its velocity threshold is greater than the velocity of mobile station.

The priority is based on the difference between received signal strength and its threshold value (i.e. RssDiff). We have taken it so because higher the RssDiff means that the MS is more nearer to the BS of that network and hence the MS can stay for more time in the cell of the respective network before asking for another handoff. Thus we are able to reduce the unnecessary handoffs and improve the overall performance of the system.

Let N= $\{n_1,n_2,n_3.........n_k\}$ is the set of available network interfaces, VT=$\{vt_1,vt_2,vt_3,.......vt_k\}$ is the set of threshold values of velocities for a mobile station for the respective networks.

RSST=$\{rsst_1,rsst_2,rsst_3,............rsst_k\}$ is the set of threshold values of received signal strengths of respective networks.

RssDiff=$\{RssDiff_1,RssDiff_2,.......rssDiff_k\}$ is the set of values of difference between the received signal strength and its threshold value.

CN = { } is the set of all eligible candidate networks into which the handoff can take place.

P=$\{0,1/k,2/k,.....j/k,...1\}$ is the set of priority values for j^th^ network, where j=1..k

The network base station (BS) and mobile station (MS) is observed for the RSS and Velocity respectively at the specified time intervals and the decisions are taken as below to select the candidate networks:

```
Let the MS is currently in network $n_i$ Then
If $RSS_i < rsst_i$ then
   For all $n_j$ where $j \neq i$
      If ($RSS_j > rsst_j$ and $v_i < vt_j$) then
         $\{CN\} = \{CN\} \cup \{n_j\}$
         $RssDiff_j=RSS_j-rsst_j$
```

The priory is assigned to all the networks as below-

Let there are n candidate networks out of k available networks then

```
For j=1 to k Do
    If j is not a candidate network Then
        $P_j=0$
    Else if j is the only candidate network Then
        $P_j=1$
Else if network is at $i^{th}$ position in an ascending order sorted set of RssDiff Then
        $p_j=i/k$;
```

Using above rule based the Network Discovery module filter the eligible networks from the all available networks.

6.4 Dynamic Decision

This module is responsible to take final decision of selecting a particular candidate networks from a set of candidate networks decided earlier by network discovery (ND) module. A dynamic score "***DScore***" is calculated for each network i as below-

$$\mathbf{DScore_i = S_i * p_i} \qquad \mathbf{(10)}$$

Where S_i is the score calculated by the NA module and p_i is the priority decided by the ND module for the i^{th} network.

A candidate networks which has highest corresponding value of "***DScore***" is selected as the "best" network to handoff.

6.5 Handoff Manager and Executor

This module is responsible for executing the handoff decisions. It handoff all the current transmissions to the network interface selected by the Dynamic Decision Module if the selected network is different from the current network. This handoff can be implemented based on any handoff Implementation techniques as described earlier in chapter 4. However, this model is more suitable to perform "Soft Vertical Handover" using application layer approaches like USHA.

Chapter 7

Simulation

7.1 Methodology

In order to evaluate and analyse the proposed decision model, we write an application in VC++ to simulate a heterogeneous network system where two cellular systems GSM & CDMA and a WLAN form an overlay structure, as shown in figure 7.1. A mobile terminal (MT) with triple network interfaces can move in the cell boundaries of any network during simulation.

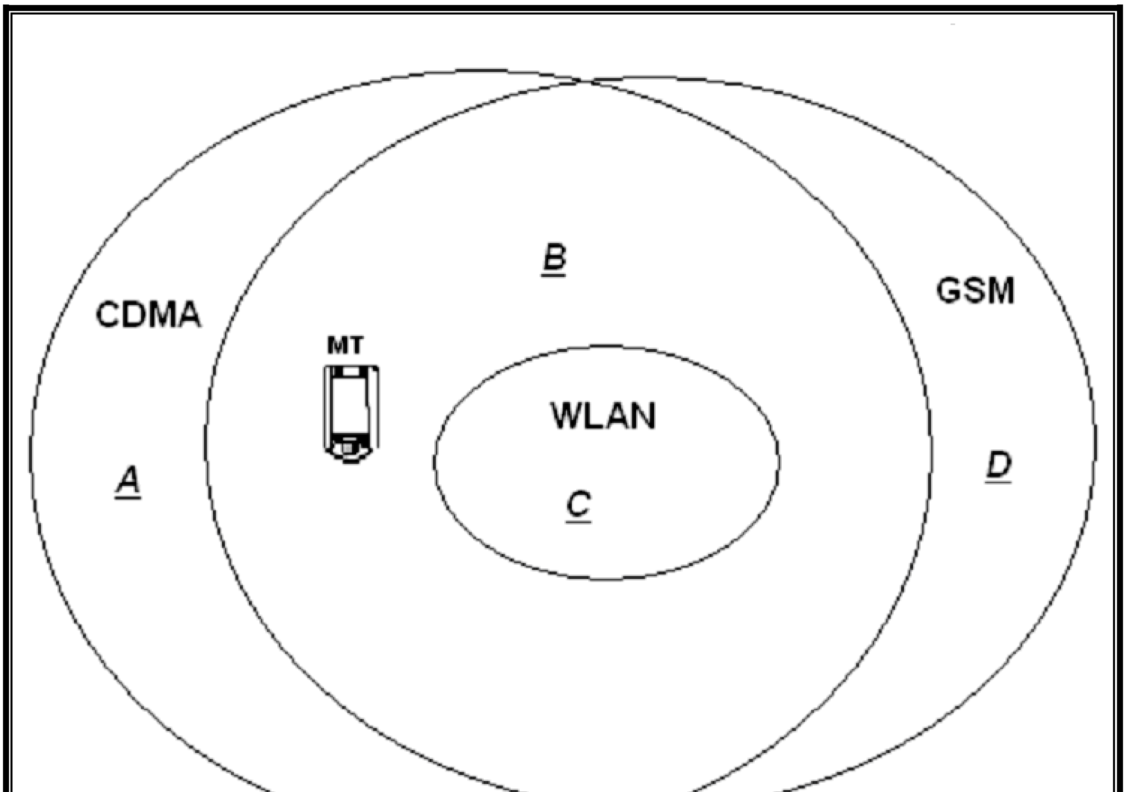


Figure 7.1: The Simulation Topology of a Heterogeneous Network

In other words, the mobile terminal MT can be in any of the regions from A, B, C and D at a moment of time and is able to access the networks as per below:
If the MT is in-

- Region A – can access only CDMA network.
- Region B – can access CDMA & GSM both.
- Region C – can access all WLAN, CDMA & GSM networks.
- Region D – can access only GSM network.

However, at one time the MT can communicate with only one network. Hence we simulated with all three possible scenario where the MT can be in WLAN or in CDMA or in GSM network at the start of simulation.

While in roaming, the mobile terminal MT monitors the networks as well as system continuously for various parameters but the handoff decision function is executed at a specified *time intervals* which is also a point of research. However, in our application we make it a variable, the value of which is provided by the user at the start of simulation.

7.2 Simulation Parameters

As we stated earlier in chapter 6, the proposed Dynamic Decision Model considers both static and dynamic parameters for taking a handoff decision. The static parameters are:

- *Offered Bandwidth* by a network,
- *Power Consumption* by a network interface and
- *Usage Cost* of a network

As all the above parameters are well advertised by the network providers and mobile terminal manufacturers, hence can be preconfigured at the time of installation of the network interface cards. These parameters are used to calculate function f_b,f_p,and f_c as per equations (3),(4)&(5) above. As these are static and remain fixed, we utilise them as “Constant” in the simulation application. The function f_b,f_p,and f_c are used further to calculate a cost function as per equation (2) after weighted by the weight factors w_b, w_p&w_c respectively based on user preferences. Hence, the weight factors w_b,w_p,& w_c are utilised as "Input Variables" in the simulation.

The dynamic parameters are: received signal strength (**rss**) and velocity (**v**) of the mobile terminal MT; which are depends on the location and mobility pattern of the MT respectively with respect to a particular base station (BS) and hence are utilised as "Random" parameters.

The parameter ***rss*** and ***v*** are compared against their threshold values ***Rsst*** and ***VT*** respectively. Hence these Rsst &VT has to be utilised and can be declared as constant or variable. However, to evaluate the proposed decision model against the variation of these threshold values also, we utilise them as "Input variables". The all the parameters and their type of utilization in the application is summarized in Table 7.1

Table 7.1:Decision Parameters

Parameter	**Utilised in application as**
Offered Bandwidth	Constant
Power Consumption	Constant
Usage Cost	Constant
Received Signal Strength	Random
Velocity	Random
Received Signal Strength Threshold (Rsst)	Input Variable
Velocity Threshold (VT)	Input Variable
Weight Factor for Bandwidth (w_b)	Input Variable
Weight Factor for Power (w_p)	Input Variable
Weight Factor for Cost (w_c)	Input Variable
No. of Handoff	Output Variable

7.3 Simulation Result

Our objective is to develop a decision model which not only can perform handoff decisions dynamically without any user intervention but also maintain the Desired Quality of Service (QoS). One of the important QoS parameter is the No. of Handoffs performed within a given time. we have also evaluated our Dynamic Decision Model based on the "No. of Handoffs" performed during a given time based on the user preferences given in terms of weight factors w_b,w_p,& w_c.

The simulation of the proposed model is carried out for WLAN, CDMA and GSM networks based on the assumed values of the parameters as mentioned in Table 7.2.

Table 7.2: Simulation Parameters

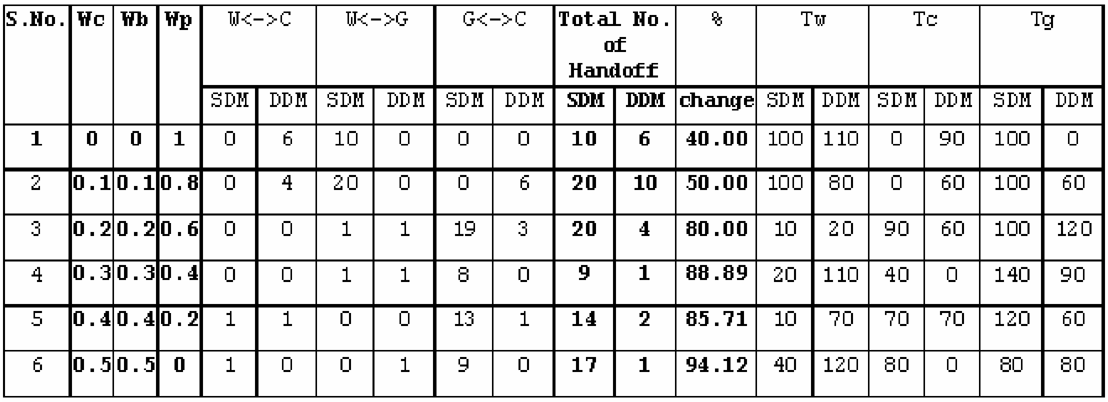
	WLAN	**GSM**	**CDMA**
Offered Bandwidth (x)	2Mbps	100kbps	150kbps
Power Consumption (y)	3hrs	2.5hrs	2hrs
Usage Cost (z)	10 Rs./min	5 Rs./min	2.5 Rs./min
Received Signal Strength Threshold (rsst)	100 dB	150 dB	125 dB
Velocity Threshold (VT)	11m/sec	13m/sec	12m/sec

The simulations are performed for both SDM (i.e. standard decision model, which does not use received signal strength and velocity in decision making) and proposed DDM (Dynamic Decision Model) and results are compared to highlight the reduction in No. of Handoffs.

Table 7.3 to 7.12 shows results in terms of the " Total No. of Handoffs", "% change in No. of handoffs" from SDM to DDM, and "Time devoted in each network by MT i.e. T_w,T_c & T_g" based on the user inputs in terms of weight factor w_b,w_p,& w_c.

Figure 7.3 to figure 7.12 presents the analysis of the respective Table data using charts. The charts show the Total No. of Handoffs versus weight factors for both Standard Decision Model (SDM) and Dynamic Decision Model (DDM).

Table 7.3: Results When Wc=Wb and current network is WLAN



S.No.	Wc	Wb	Wp	W<->C		W<->G		G<->C		Total No. of Handoff		%	Tw		Tc		Tg	
				SDM	DDM	SDM	DDM	SDM	DDM	**SDM**	**DDM**	**change**	SDM	DDM	SDM	DDM	SDM	DDM
1	**0**	**0**	**1**	0	6	10	0	0	0	**10**	**6**	**40.00**	100	110	0	90	100	0
2	**0.1**	**0.1**	**0.8**	0	4	20	0	0	6	**20**	**10**	**50.00**	100	80	0	60	100	60
3	**0.2**	**0.2**	**0.6**	0	0	1	1	19	3	**20**	**4**	**80.00**	10	20	90	60	100	120
4	**0.3**	**0.3**	**0.4**	0	0	1	1	8	0	**9**	**1**	**88.89**	20	110	40	0	140	90
5	**0.4**	**0.4**	**0.2**	1	1	0	0	13	1	**14**	**2**	**85.71**	10	70	70	70	120	60
6	**0.5**	**0.5**	**0**	1	0	0	1	9	0	**17**	**1**	**94.12**	40	120	80	0	80	80

Here: W<->C: No. of handoff from WLAN to CDMA and vice-versa.
W<->G: No. of handoff from WLAN to CDMA and vice-versa.
G<->C: No. of handoff from GSM to CDMA and vice-versa.

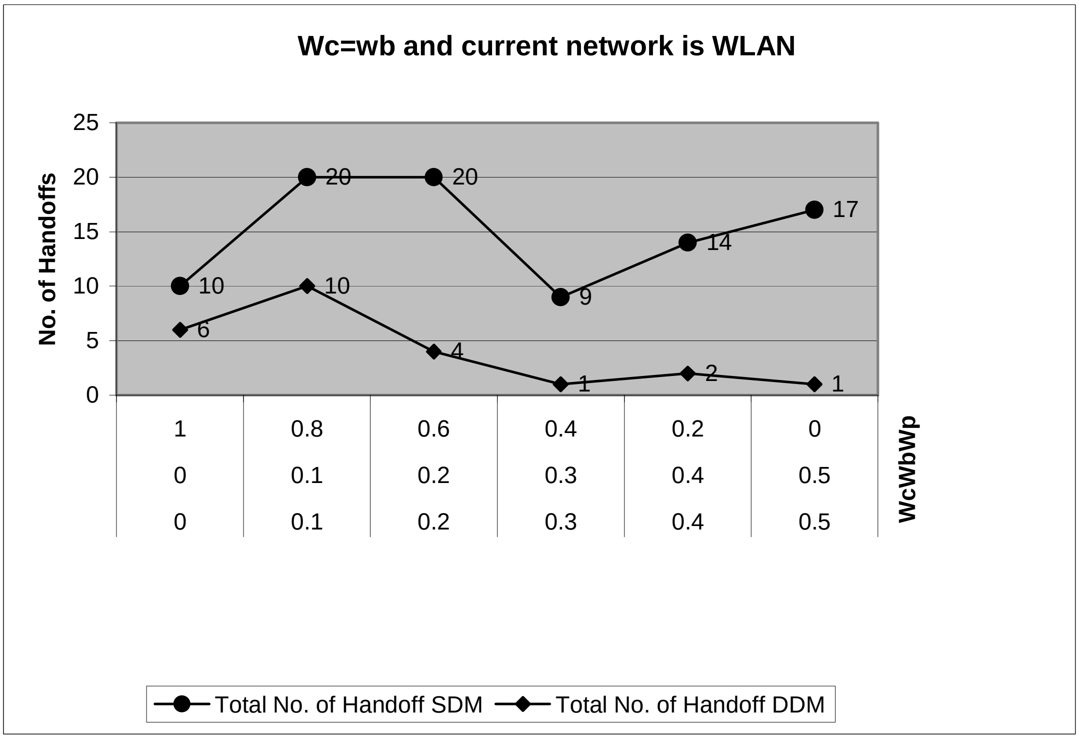


Figure 7.3: No. of handoff versus weight factor when Wc=Wb

Table 7.4: Results When Wc=Wp and current network is WLAN

S.No.	Wc	Wb	Wp	W<->C		W<->G		G<->C		Total No. of Handoff		%	Tw		Tc		Tg	
				SDM	DDM	SDM	DDM	SDM	DDM	SDM	DDM	change	SDM	DDM	SDM	DDM	SDM	DDM
1	**0**	**1**	**0**	0	1	1	0	17	2	**18**	**3**	**83.33**	30	60	80	80	90	60
2	**0.1**	**0.8**	**0.1**	0	0	1	1	12	1	**13**	**2**	**84.62**	10	100	60	40	130	60
3	**0.2**	**0.6**	**0.2**	0	1	1	0	11	3	**12**	**4**	**66.67**	30	50	50	100	120	50
4	**0.3**	**0.4**	**0.3**	0	1	0	1	11	5	**12**	**6**	**50.00**	10	30	60	80	130	90
5	**0.4**	**0.2**	**0.4**	1	1	0	0	13	1	**14**	**2**	**85.71**	10	70	70	70	120	60
6	**0.5**	**0**	**0.5**	1	0	0	1	12	3	**13**	**4**	**69.23**	20	60	60	60	120	80

Here: W<->C: No. of handoff from WLAN to CDMA and vice-versa.
W<->G: No. of handoff from WLAN to CDMA and vice-versa.
G<->C: No. of handoff from GSM to CDMA and vice-versa.

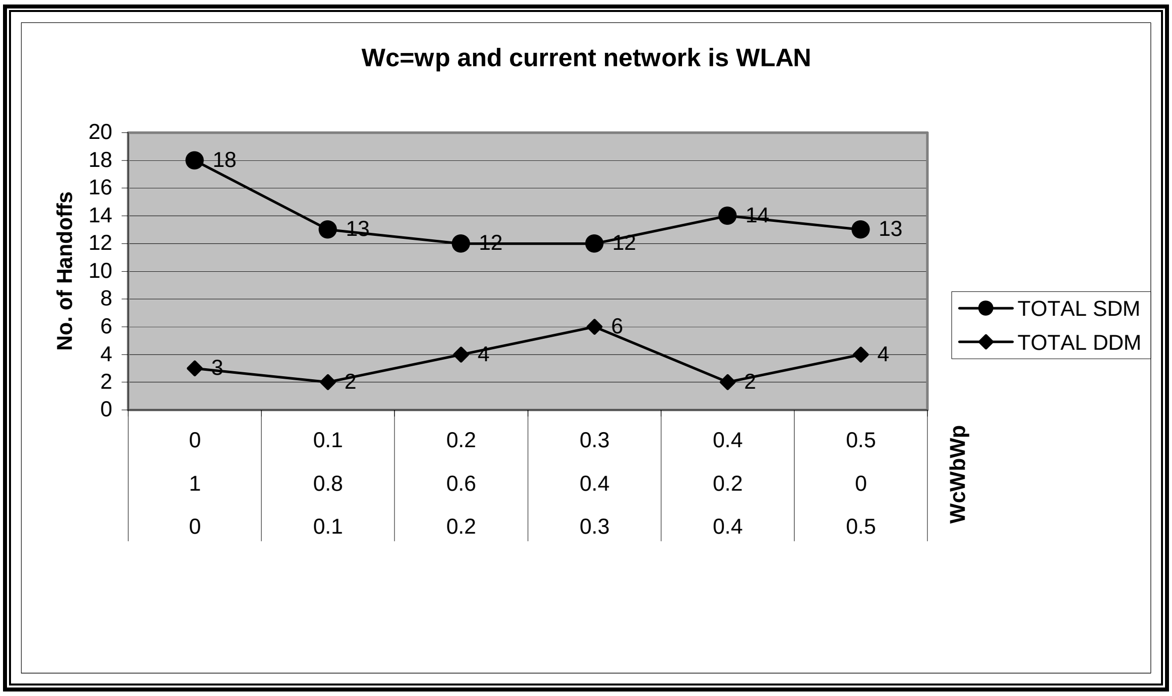


Figure 7.4: No. of handoff versus weight factor when Wc=Wb

Table 7.5: Results When Wb=Wp and current network is WLAN

S.No.	Wc	Wb	Wp	W<->C		W<->G		G<->C		Total No. of Handoff		%	Tw		Tc		Tg	
				SDM	DDM	SDM	DDM	SDM	DDM	SDM	DDM	change	SDM	DDM	SDM	DDM	SDM	DDM
1	**1**	**0**	**0**	1	1	0	0	12	1	**13**	**2**	**84.62**	20	80	60	80	120	40
2	**0.8**	**0.1**	**0.1**	1	1	0	0	16	1	**17**	**2**	**88.24**	40	100	80	70	80	30
3	**0.6**	**0.2**	**0.2**	1	1	0	0	9	4	**10**	**5**	**50.00**	30	40	50	80	120	80
4	**0.4**	**0.3**	**0.3**	1	2	0	2	17	2	**18**	**6**	**66.67**	30	80	90	60	80	60
5	**0.2**	**0.4**	**0.4**	0	0	1	1	12	2	**13**	**3**	**76.92**	20	100	60	50	120	50
6	**0**	**0.5**	**0.5**	0	0	1	1	18	1	**19**	**2**	**89.47**	20	80	90	40	90	40

Here: W<->C: No. of handoff from WLAN to CDMA and vice-versa.
W<->G: No. of handoff from WLAN to CDMA and vice-versa.
G<->C: No. of handoff from GSM to CDMA and vice-versa.

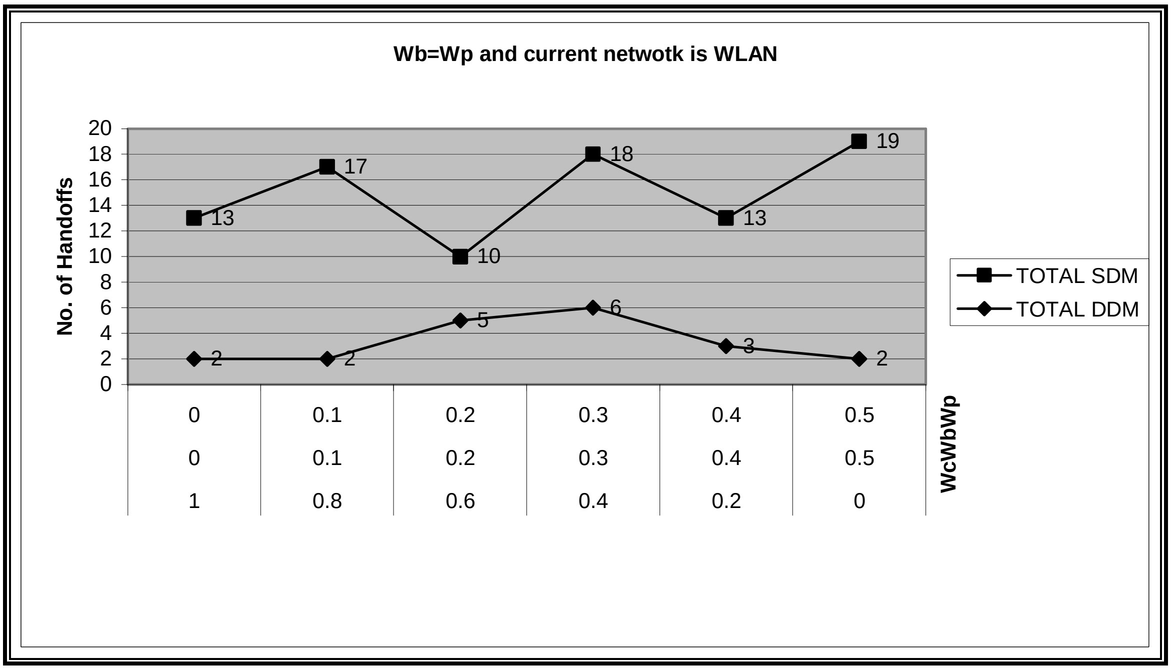


Figure 7.5: No. of handoff versus weight factor when Wc=Wb

Table 7.6: Results When Wc=Wb and current network is CDMA

S.No.	**Wc**	**Wb**	**Wp**	W<->C		W<->G		G<->C		**Total No. of Handoff**		**%**	Tw		Tc		Tg	
				SDM	DDM	SDM	DDM	SDM	DDM	**SDM**	**DDM**	**change**	SDM	DDM	SDM	DDM	SDM	DDM
1	**0**	**0**	**1**	1	2	9	0	0	0	**10**	**2**	**80.00**	150	80	10	120	40	0
2	**0.1**	**0.1**	**0.8**	0	0	6	5	1	1	**7**	**6**	**14.29**	90	80	10	30	100	90
3	**0.2**	**0.2**	**0.6**	0	0	0	1	13	1	**13**	**2**	**84.62**	0	40	70	80	130	80
4	**0.3**	**0.3**	**0.4**	0	0	0	2	13	4	**13**	**6**	**53.85**	0	10	0	100	130	90
5	**0.4**	**0.4**	**0.2**	0	0	0	1	10	3	**10**	**5**	**50.00**	0	40	50	80	150	80
6	**0.5**	**0.5**	**0**	6	0	0	7	20	7	**20**	**20**	**0.00**	0	60	100	70	100	70

Here: W<->C: No. of handoff from WLAN to CDMA and vice-versa.
W<->G: No. of handoff from WLAN to CDMA and vice-versa.
G<->C: No. of handoff from GSM to CDMA and vice-versa.

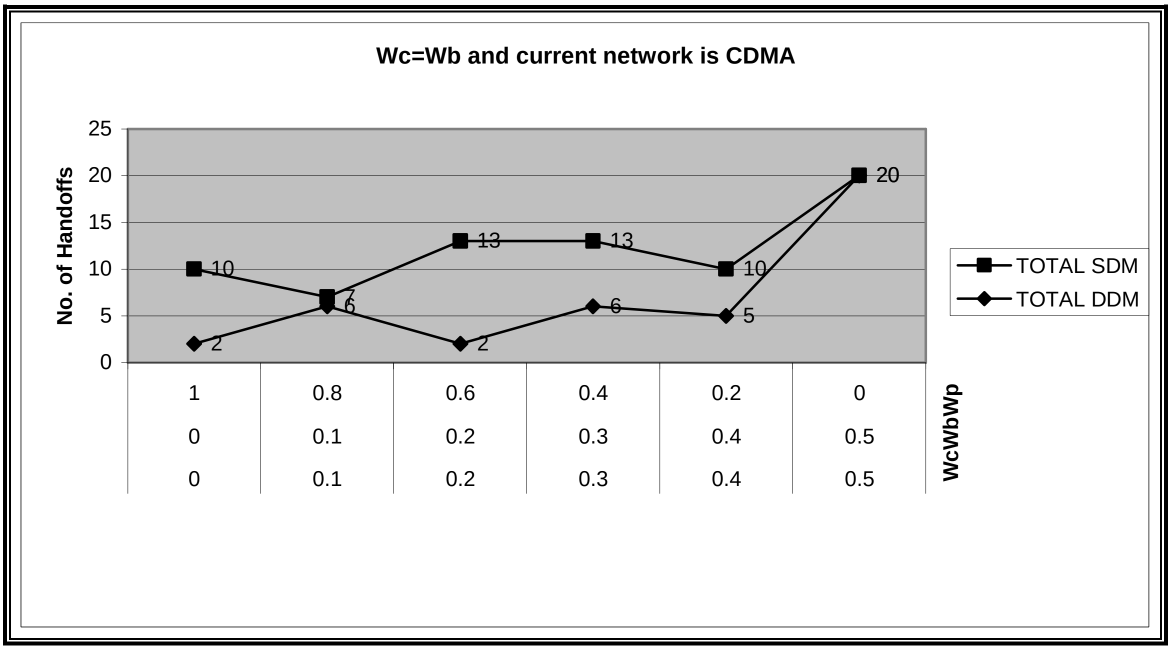


Figure 7.6: No. of handoff versus weight factor when Wc=Wb

Table 7.7: Results When Wc=Wp and current network is CDMA

S.No.	**Wc**	**Wb**	**Wp**	W<->C		W<->G		G<->C		**Total No. of Handoff**		%	Tw		Tc		Tg	
				SDM	DDM	SDM	DDM	SDM	DDM	**SDM**	**DDM**	**change**	SDM	DDM	SDM	DDM	SDM	DDM
1	**0**	**1**	**0**	0	1	0	0	10	3	**10**	**5**	**50.00**	0	80	50	60	150	60
2	**0.1**	**0.8**	**0.1**	0	0	0	1	20	1	**20**	**2**	**90.00**	0	80	100	60	100	60
3	**0.2**	**0.6**	**0.2**	0	1	0	1	10	1	**10**	**3**	**70.00**	0	160	50	20	150	20
4	**0.3**	**0.4**	**0.3**	0	0	0	1	13	1	**13**	**2**	**84.62**	0	50	70	90	130	60
5	**0.4**	**0.2**	**0.4**	0	1	0	1	20	18	**20**	**20**	**0.00**	0	10	100	100	100	90
6	**0.5**	**0**	**0.5**	0	0	0	2	20	8	**20**	**10**	**50.00**	0	20	100	80	100	100

Here: W<->C: No. of handoff from WLAN to CDMA and vice-versa.
W<->G: No. of handoff from WLAN to CDMA and vice-versa.
G<->C: No. of handoff from GSM to CDMA and vice-versa.

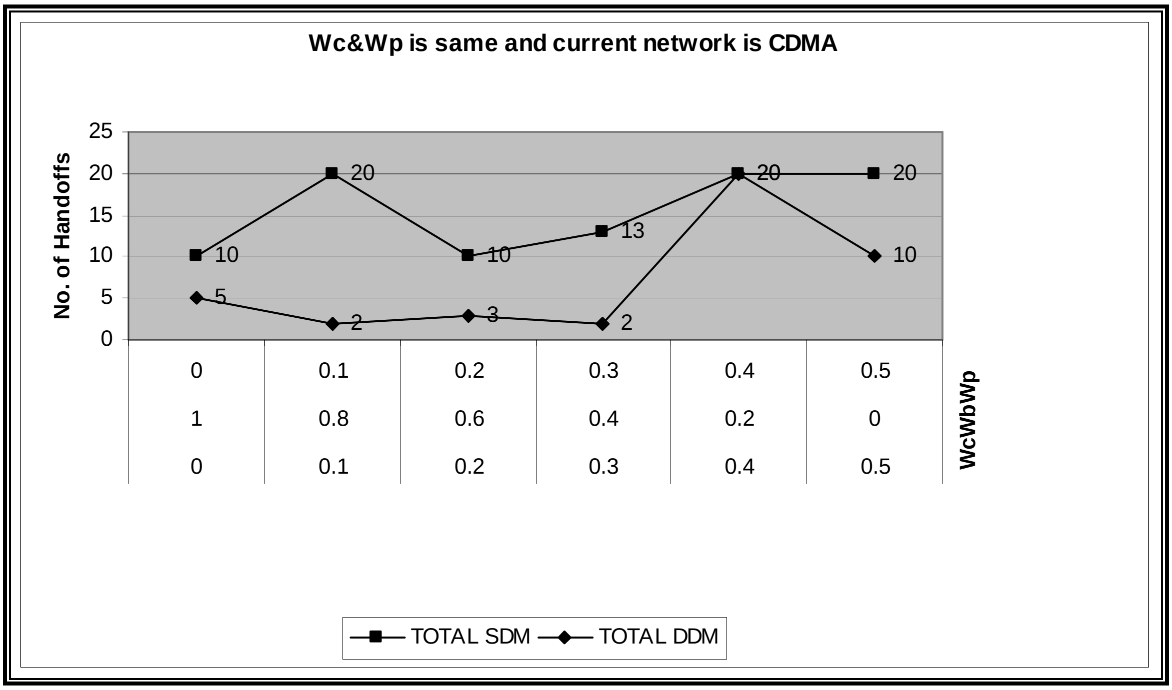


Figure 7.7: No. of handoff versus weight factor when Wc=Wb

Table 7.8: Results When Wb=Wp and current network is CDMA

S.No.	**Wc**	**Wb**	**Wp**	W<->C		W<->G		G<->C		**Total No. of Handoff**		%	Tw		Tc		Tg	
				SDM	DDM	SDM	DDM	SDM	DDM	**SDM**	**DDM**	**change**	SDM	DDM	SDM	DDM	SDM	DDM
1	**1**	**0**	**0**	0	2	0	3	8	3	**8**	**8**	**0.00**	0	80	40	90	160	30
2	**0.8**	**0.1**	**0.1**	0	3	0	3	16	4	**16**	**10**	**37.50**	0	60	80	80	120	60
3	**0.6**	**0.2**	**0.2**	0	3	0	3	20	4	**20**	**10**	**50.00**	0	60	100	80	100	60
4	**0.4**	**0.3**	**0.3**	0	1	0	1	20	3	**20**	**5**	**75.00**	0	40	100	80	100	80
5	**0.2**	**0.4**	**0.4**	0	0	0	2	8	2	**8**	**4**	**50.00**	0	60	40	60	160	80
6	**0**	**0.5**	**0.5**	0	1	0	1	13	2	**13**	**4**	**69.23**	0	50	70	100	130	50

Here: W<->C: No. of handoff from WLAN to CDMA and vice-versa.
W<->G: No. of handoff from WLAN to CDMA and vice-versa.
G<->C: No. of handoff from GSM to CDMA and vice-versa.

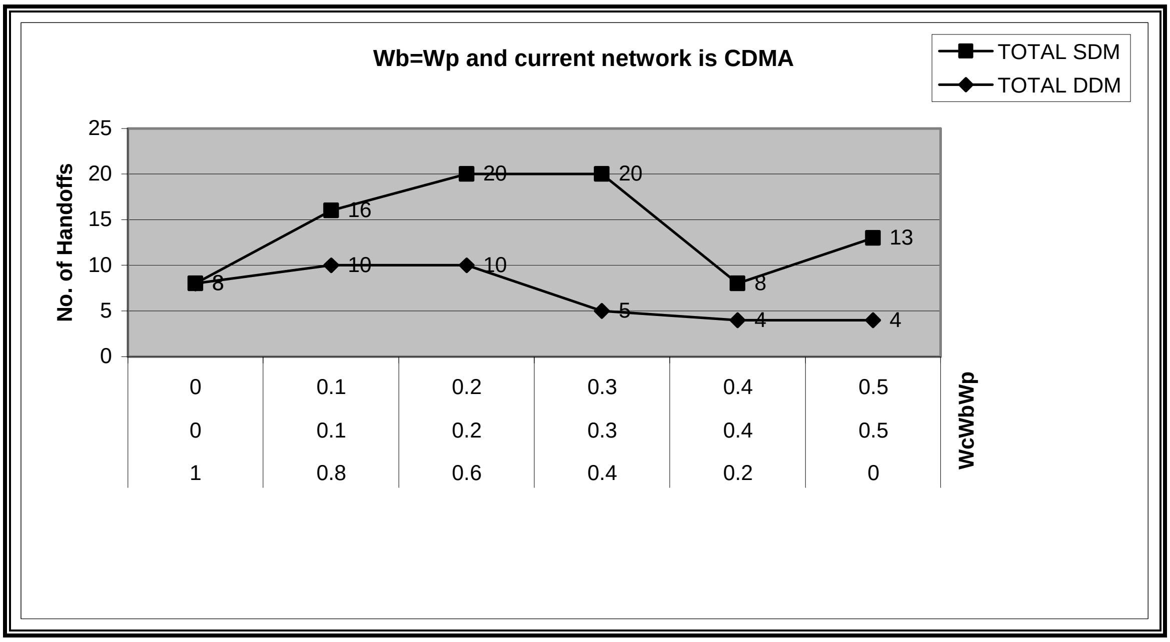


Figure 7.8: No. of handoff versus weight factor when Wc=Wb

Table 7.9: Results When Wc=Wb and current network is GSM

S.No.	Wc	Wb	Wp	W<->C		W<->G		G<->C		Total No. of Handoff		%	Tw		Tc		Tg	
				SDM	DDM	SDM	DDM	SDM	DDM	SDM	DDM	change	SDM	DDM	SDM	DDM	SDM	DDM
1	0	0	1	0	4	10	2	0	2	10	8	20.00	100	70	0	70	100	60
2	0.1	0.1	0.8	0	2	8	2	0	3	8	7	12.50	80	80	0	90	120	30
3	0.2	0.2	0.6	0	1	0	1	13	2	13	4	69.23	0	50	60	70	140	80
4	0.3	0.3	0.4	0	0	0	0	10	2	10	2	80.00	0	0	50	100	150	100
5	0.4	0.4	0.2	0	0	0	0	13	2	13	2	84.62	0	0	60	80	140	120
6	0.5	0.5	0	0	1	0	1	20	18	20	20	0.00	0	10	100	90	100	100

Here: W<->C: No. of handoff from WLAN to CDMA and vice-versa.
W<->G: No. of handoff from WLAN to CDMA and vice-versa.
G<->C: No. of handoff from GSM to CDMA and vice-versa.

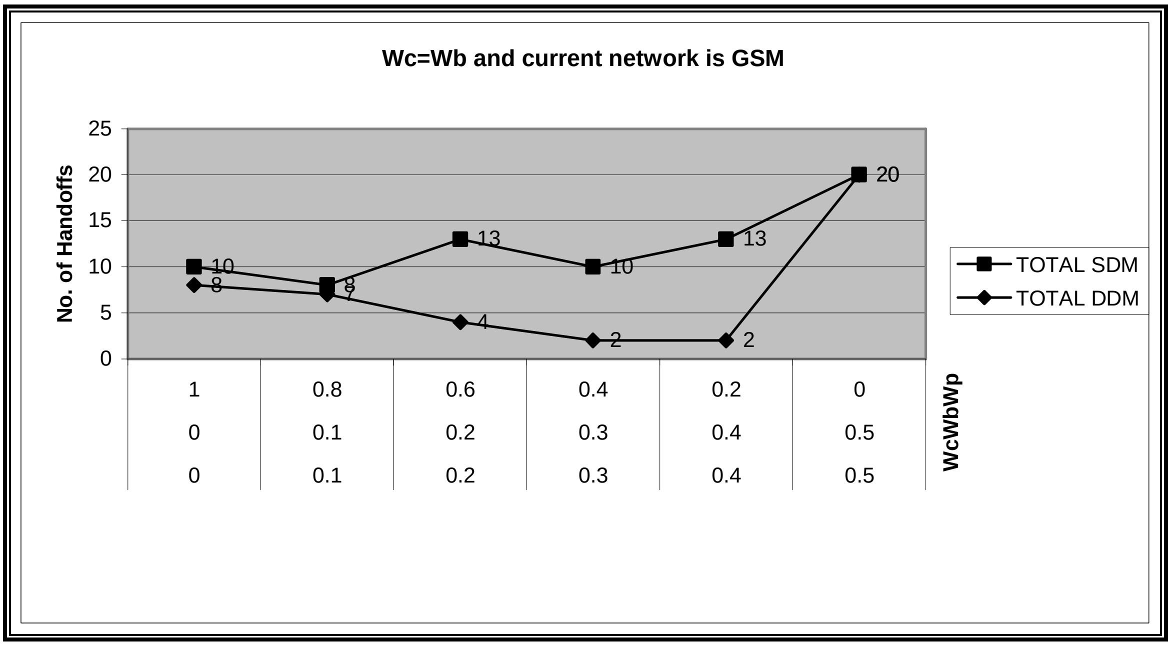


Figure 7.9: No. of handoff versus weight factor when Wc=Wb

Table 7.10: Results When Wc=Wp and current network is GSM

S.No.	**Wc**	**Wb**	**Wp**	W<->C		W<->G		G<->C		**Total No. of Handoff**		%	Tw		Tc		Tg	
				SDM	DDM	SDM	DDM	SDM	DDM	**SDM**	**DDM**	**change**	SDM	DDM	SDM	DDM	SDM	DDM
1	**0**	**1**	**0**	0	1	0	1	13	2	**13**	**4**	**69.23**	0	50	60	50	140	100
2	**0.1**	**0.8**	**0.1**	0	0	0	0	13	1	**13**	**1**	**92.31**	0	0	60	90	140	110
3	**0.2**	**0.6**	**0.2**	0	1	0	1	20	3	**20**	**5**	**75.00**	0	20	100	90	100	90
4	**0.3**	**0.4**	**0.3**	0	0	0	2	20	15	**20**	**17**	**15.00**	0	10	100	70	100	120
5	**0.4**	**0.2**	**0.4**	0	2	0	2	10	4	**10**	**8**	**20.00**	0	20	50	70	150	110
6	**0.5**	**0**	**0.5**	0	0	0	1	13	2	**13**	**3**	**76.92**	0	20	40	60	160	120

Here: W<->C: No. of handoff from WLAN to CDMA and vice-versa.
W<->G: No. of handoff from WLAN to CDMA and vice-versa.
G<->C: No. of handoff from GSM to CDMA and vice-versa.

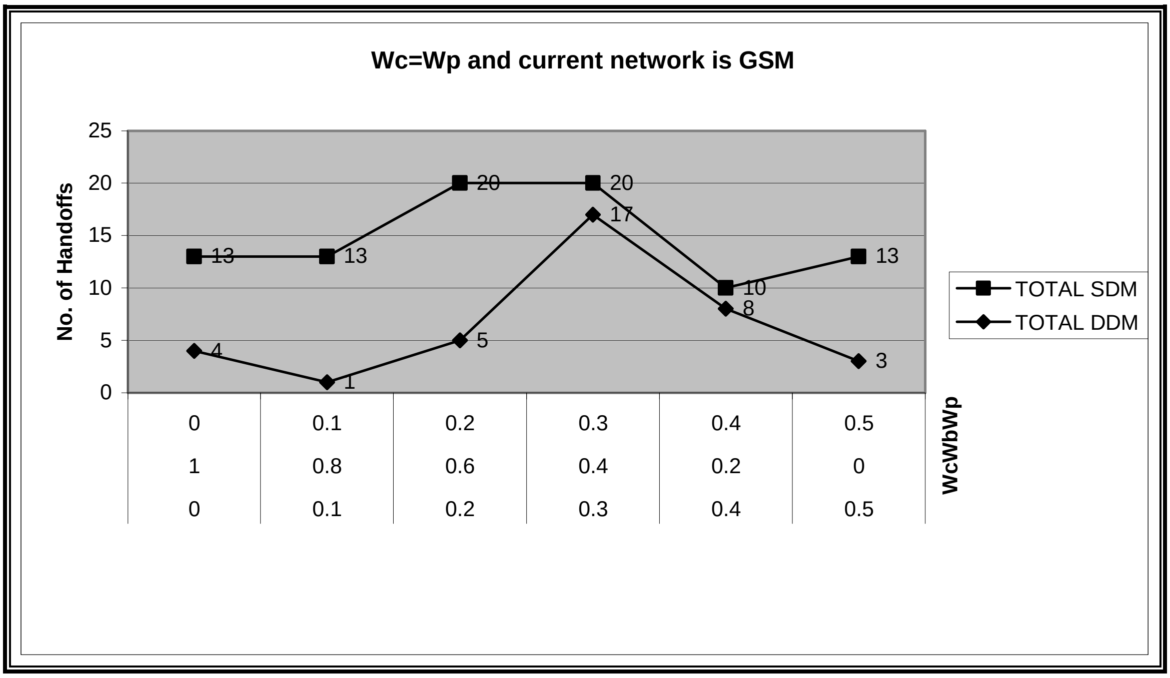


Figure 7.10: No. of handoff versus weight factor when Wc=Wb

Table 7.11: Results When Wb=Wp and current network is GSM

S.No.	Wc	Wb	Wp	W<->C		W<->G		G<->C		Total No. of Handoff		%	Tw		Tc		Tg	
				SDM	DDM	SDM	DDM	SDM	DDM	SDM	DDM	change	SDM	DDM	SDM	DDM	SDM	DDM
1	1	0	0	0	0	0	0	10	2	10	2	80.00	0	0	50	80	150	120
2	0.8	0.1	0.1	0	0	0	0	20	2	20	2	90.00	0	0	100	100	100	100
3	0.6	0.2	0.2	0	0	0	0	20	2	20	2	90.00	0	0	100	80	100	120
4	0.4	0.3	0.3	0	0	0	1	20	2	20	3	85.00	0	50	100	50	100	100
5	0.2	0.4	0.4	0	1	0	1	20	8	20	10	50.00	0	20	100	80	100	100
6	0	0.5	0.5	0	0	0	0	13	1	13	1	92.31	0	0	60	80	140	120

Here: W<->C: No. of handoff from WLAN to CDMA and vice-versa.
W<->G: No. of handoff from WLAN to CDMA and vice-versa.
G<->C: No. of handoff from GSM to CDMA and vice-versa.

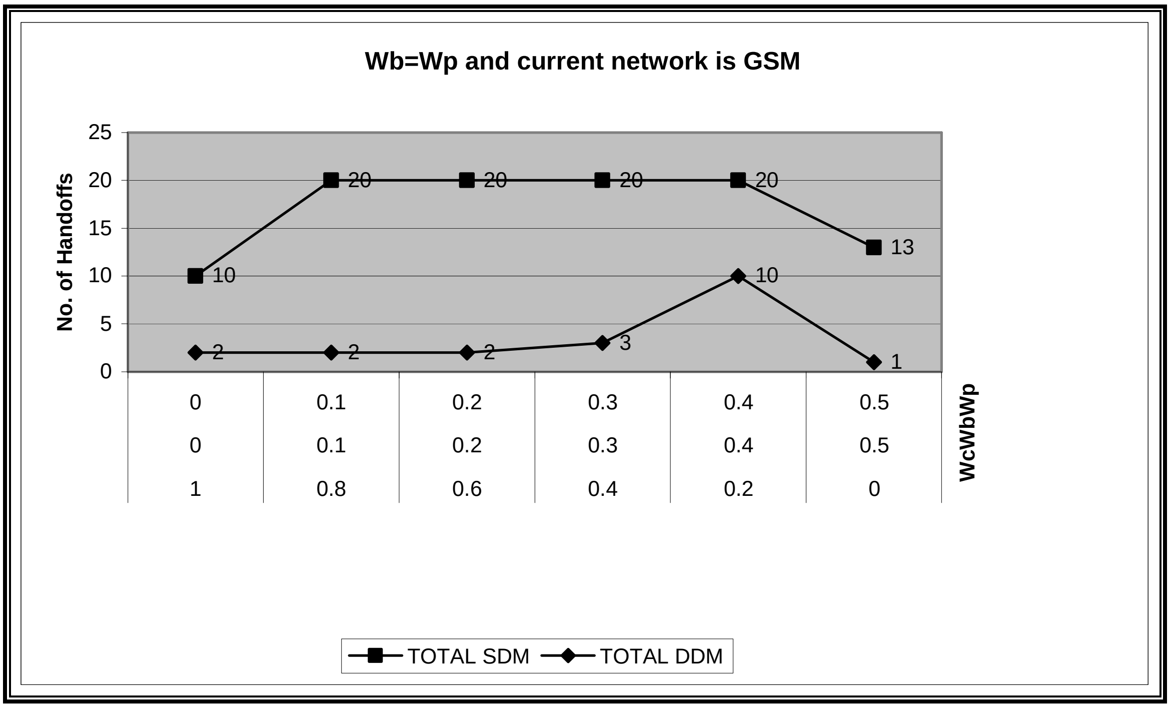


Figure 7.11: No. of handoff versus weight factor when Wc=Wb

7.4 Result Analysis

The Simulation results from Table 7.3 to 7.11 demonstrate that the DDM performs the vertical handoffs less frequently than the SDM method which does not consider ***Rss*** and ***Velocity*** as handoff criteria for handoff decisions. In other words, the "No. of Handoffs" performed by a roaming mobile terminal during a given time using DDM is less as compared to the "No. of Handoffs" performed using SDM method. The results obtained shows that, the "No. of Handoffs" performed in DDM is reduced by 50% to 60% from the "No. of Handoffs" performed using SDM.

The reduced "no. of handoffs" means less "ping-pong" effect. Ping-pong occurs when multiple handoff decisions are triggered in a short period. A wrong decision causes multiple handoff decisions (a ping-pong) e.g. a handoff to a network which can not support the current speed of the mobile terminal. It reflects the stability of the system.

Hence, simulation result correctly shows that the proposed dynamic decision model is able to reduce the unnecessary handoffs and thus improve the system stability and performance.

Chapter 8

Conclusion and Future Work

Conclusion

In this major project, we have proposed, develop and simulate a *Dynamic Decision Model* which is performing the vertical handoffs to the “Best” interface at the “best” time moment successfully and fficiently.

The *Dynamic Decision Model (DDM)* for VHO adopts a three phase approach comprising Priority phase, Normal phase and Decision phase. The P*riority Phase*, discover all available networks, filter out ineligible networks based on RSS & velocity and then assign the priorities to all eligible candidate networks using the difference between RSS and its threshold value RSST where Higher the difference, higher the priority. The *Normal phase* record the system information and user preferences for offered bandwidth, battery power, and network usage in terms of respective weight factors w_b, w_p,& w_c where higher the preference, higher the value of weight factor**.** It then calculates a cost function for each candidate network**.** Finally, the *Decision phase* calculates a Score function, by multiplying the priority from priority phase and cost function from normal phase, for each candidate network. It then select a network having the highest value of score function as “Best” network to handoff and transfer all the current transmissions to selected network if different from the current network.

This Dynamic Decision Model is simple and applicable with any handoff Implementation techniques as described in chapter 4. However, this model is more suitable to perform “Soft Vertical Handoffs” using application layer approaches like USHA.

The proposed *Dynamic Decision Model* is simulated in VC++ for a heterogeneous network system where two cellular systems GSM & CDMA and a WLAN form an overlay structure. The results of DDM are analysed and compared with the results of Standard Decision Model (SDM) which proves the effectiveness of the DDM.

A rule based approach is used to relate the Received signal strength (RSS) of a network and the velocity of the mobile station. *In our best knowledge, this is first such effort of using RSS with "velocity" for making vertical handoff decisions.*

Future Work

Further research can be conducted to transform this *Rule Based* relation into a *function* which can relate the RSS with the velocity, So that the function can be utilized directly with other factors in making vertical handoff decisions. Also, This Dynamic Decision Model has not yet taken running applications into consideration. We can think of the following application categories: bulk transfer (e.g. ftp), interactive (e.g. telnet), real-time (e.g. audio conferencing), and bandwidth intensive (e.g. video conferencing). Users can specify, the priorities for each category and applications belonging to each category. The weights for each parameter in cost function can be per network and per application. Hence, transforming the rule based into a function and incorporating the running application categories as part of decision process may be considered for future work.

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