OPTIMIZING NETWORK ACCESS SELECTION IN WIRELESS HETEROGENEOUS NETWORKS USING VELOCITY, LOCATION, POLICY AND QoS DETAILS

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Abstract

Optimizing Network Access Selection in Wireless Heterogeneous Networks using Velocity, Location, Policy and QoS Details

Xavier Francis

As the interest in 4G communication systems continues to grow, both academia and industry agree that a symbiotic relationship between various wireless systems is required to provide continuous broadband coverage to mobile users. It is generally accepted that a single wireless access technology alone will be incapable of meeting the various requirements of mobility, data rate and coverage in the future. Future wireless systems are envisioned as being heterogeneous in that they will include a combination of various wireless access technologies such as 3G, WLAN, and WiMAX and will have a common IP core.

To fully utilize the various resources and maintain seamless connectivity in the future heterogeneous wireless environment, intelligent handoff schemes that are flexible, scalable and proactive are essential. Therefore, a new handoff decision method, one that works in a novel business model—Heterogeneous Wireless Service Provider (HWSP)—was developed with an aim to improve the mobile user's user experience. More effort was spent to achieve a good level of user satisfaction, by making the entire selection process automatic, and the user oblivious of the underlying network selection intricacies. The algorithm is able to make the final network decision, based on any particular user's speed, location, QoS demands and preference policies. This allows the algorithm to prevent unwanted handoffs and reduce the cost associated with connecting to suboptimal networks.

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List of Acronyms

3G-LTE	3rd Generation Long Term Evolution
3GPP	3rd Generation Partnership Project
3GPP2	3rd Generation Partnership Project 2
AAA	Authentication Authorization Accounting
AHP	Analytic Hierarchy Process
AMPS	Advanced Mobile Phone System
AP	Access Point
AT	Application Threshold
AT&T	American Telephone & Telegraph
BAN	Basic Access Network
BAS	Basic Access Signalling
BS	Base Station
CCSA	China Communication Standards Association
CRTC	Canadian Radio-television Telecommunications Commission
D-AMPS	Digital Advanced Mobile Phone System
DECT	Digital Enhanced Cordless Telecommunications
DoD	Department of Defence
EDA	Embedded Decision Algorithm
EDGE	Enhanced Data rate for GSM Evolution
ESS	Extended Service Set
EU-IST	European Union-Information Society Technologies
EV-DO	Evolution-Data Optimized
EWC	Enhanced Wireless Consortium
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
FMIPV6	Fast Handovers for Mobile IP Version 6
GIS	Global Information System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GRA	Grey Relational Analysis
GSM	Global System for Mobile communications
HIS	Hybrid Information System
HMIPV6	Hierarchical Mobile IP Version 6
HSDPA	High-Speed Downlink Packet Access
HWSP	Heterogeneous Wireless Service Provider
iDEN	Integrated Digital Enhanced Network
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IETF-DNA	Internet Engineering Task Force-Detecting Network Attachment
IMT-2000	International Mobile Telecommunications 2000 initiative
MMUT	Mobile Multi-interface User Terminal
IP	Internet Protocol

IRTF	Internet Research Task Force
IS-136	Interim Standard-136
IS-95	Interim Standard-95
ISP	Internet Service Provider
ITU	International Telecommunication Union
LBS	Location Based Services
LIS	Location Information Server
LVM	Location Velocity Module
MADM	Multi Attribute Decision Making
ME	Mobile Equipment
MEP	Minimum Entry Policy
MGIS	Mobile Geographical Information System
MIH	Media Independent Handover
MIMO	Multiple-Input Multiple-Output
MIPSHOP	Mobility for IP: Performance Signalling and Handoff Optimization
MMS	Multimedia Messaging Service
MobOpts	IP Mobility Optimizations
MSC	Mobile Switching Centre
MTP	Minimum Threshold Policy
NAI	Network Access Identifier
NMT	Nordic Mobile Telephone
NS-2	Network Simulator 2
NSIS	Next Steps in Signalling
NTT	Nippon Telegraph & Telephone Corporation
OFDM	Orthogonal Frequency Division Multiplexing
PANA	Protocol for carrying Authentication for Network Access
PDA	Personal Data Assistants
PDC	Personal Digital Cellular
PEP	Policy Enforcement Point
PLMN	Public Land Mobile Network
QoS	Quality of Service
RAN	Radio Access Network
RDA	Remote Decision Algorithm
RSS	Radio Signal Strength
RSVP	Resource Reservation Protocol
RTT	Transmission Technology
SCS	Seamless Connection Server
SDR	Software Defined Radio
SDSS	Spatial Decision Support System
SIM	Subscriber Identity Module
SLA	Service Level Agreements
SOHWE	Service Oriented Heterogeneous Wireless Network Environment
TACS	Total Access Communications System
TDMA	Time Division Multiple Access
TD-SCDMA	Time Division-Synchronous Code Division Multiple Access
UMTS	Universal Mobile Telecommunications System

UWC-136	Universal Wireless Communications 136
WCDMA	Wideband Code Division Multiple Access
WG	Working Group

Chapter 1

Introduction

1.1 Problem Overview

The wireless cellular phone market has experienced unprecedented growth ever since its inception. According to the International Telecommunication Union (ITU), the number of cellular phone users has grown dramatically from 215 million in 1997 to about 3.3 billion in 2007 [ITU08]. Due to this increase in demand a broad range of cellular technologies—such as Global System for Mobile communications (GSM), Code Division Multiple Access 2000 (CDMA2000) and Universal Mobile Telecommunications System (UMTS)—has been developed. With this surge in demand for cellular technology the need for these technologies to provide a broader range of services has also risen. No longer is cellular technology limited to carrying voice packets; it has successfully evolved to carry data packets as well. Today technology improvements such as Evolution-Data Optimized (EV-DO) and High-Speed Downlink Packet Access (HSDPA) can provide data rates that exceed 3 megabits per second (Mbps). The growth in the cellular wireless market was paralleled by a growth in other wireless access technologies.

The wireless access technologies that have gained the most attention are Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX) and Bluetooth. Among these technologies, WLAN was standardized in the 1990's and became an immediate success. This can be partly attributed to the development of laptops with WLAN cards. It should be noted that all these new wireless access technologies are inherently different from one another in terms of their capabilities and applications.

Work to integrate cellular networks with other access networks started with an effort to integrate cellular and WLAN networks. Several interworking architectures between cellular and WLAN systems exist today. The Third Generation Partnership Project's (3GPP) 3GPP-WLAN interworking architecture [3GP04] is one among them. These efforts are considered promising, because integration could help solve the problem of low data rate faced by the cellular networks and at the same time increase the limited coverage of the Wi-Fi networks. As more and more wireless access technologies emerged so did the need to combine them to facilitate user movement across these different access networks. This integration led to the birth of the "seamless mobility" concept.

As the interest in 4G communication systems continues to grow, both academia and industry agree that a symbiotic relationship between various wireless systems is required to provide continuous broadband coverage to mobile users. It is generally accepted that a single wireless access technology alone will be incapable of meeting the various requirements of mobility, data rate and coverage in the future. Future wireless systems are envisioned as being heterogeneous in that they will include a combination of various wireless access technologies such as 3G, WLAN, and WiMAX and will have a common IP core. The mobile nodes will be equipped with multiple access network cards and users will be able to roam transparently over the network in a seamless manner [OPJ05].

In a typical cellular wireless environment, handoffs are used to provide coverage continuity and load balancing and to satisfy specialized QoS demands by the user. A conventional handoff is used to change the Mobile Equipment's (ME) connection point to the core network from one base station (channel) or Access Point (AP) to the other [WEL84]. These handoffs are often initiated when crossing a cell boundary or when the quality of the signal from the current base station or AP deteriorates.

Well designed handoff schemes exist for cellular networks to provide uninterrupted connectivity with good Quality of Service (QoS) [ADK05]. In contrast, handoffs in heterogeneous wireless environments (environments with more than one type of access network) are more complex and are still actively being researched. The need for an intelligent handoff algorithm is more acute in a heterogeneous environment for the following reasons: the difference in QoS provided by various access technologies, the fluctuating user demand and the inherent dynamic nature of the wireless link. Even though handoffs are essential for maintaining connectivity, poorly designed handoff schemes tend to generate very heavy signaling traffic and can decrease the overall QoS. They could cause severe data interruptions and degradation in performance [ZMF95]. In contrast to the cellular wireless environment, the handoffs in heterogeneous environments are not performed for coverage or service continuity reasons alone. They also play a vital role in optimizing the performance of the entire system. To fully utilize the various resources in a heterogeneous environment, handoff schemes that are proactive and flexible are needed.

Selecting the best possible interface from an array of inherently different access technologies to satisfy the QoS needs of the user is called network selection [MEL08]. Handoff algorithms and network selection are related because every time a ME needs to perform a handoff it is faced with the network selection problem. The network selection problem is a field of active research and is a relatively new domain. A survey of the network selection problem shows that there is significant work done in this field, but at the same time there are still many open issues that are to be addressed.

In the survey of the solutions to solve the network selection problem, it was noted that location information is vital to perform effective handoffs. It was also found that policy information is quintessential to represent intricate user demands. Most of the handoff schemes in the literature fail to consider the user's velocity. There is also disagreement as to where the decision process should take place by utilizing QoS hints. After analyzing the arguments favoring the placement of decision intelligence at the mobile equipment side and at the network side, it was concluded that both approaches have their benefits and drawbacks.

It was observed that a new approach of placing the decision intelligence at both the mobile equipment side and the network side, and then triggering them based on the user velocity is more effective. There needs to be an effort to combine all the relevant factors and come up with algorithms that are flexible, scalable and proactive. It was observed that for seamless mobility to take off there is a need for new intelligent handoffs schemes, business models and even compromises on the part of the vendors and service providers to bring the different access networks together.

1.2 Thesis Objectives and Scope

To make good on the promise of seamless coexistence of different access networks, a number of technical and logistical issues have to be resolved. Among these issues an important issue, if not the most important one, is the network selection problem. It is crucial to solve the network selection problem because without the opportunity to switch to networks that are better or more capable the user will not risk changing his point of attachment and thus will render the entire seamless mobility concept useless. The emphasis of this thesis is to develop a decision method that can utilize both ME and network side resources and help the user solve the network selection problem by combining techniques that are novel and state of the art.

The network selection can be further broken into three major parts: discovery, decision and selection. The discovery stage involves discovering available candidate access networks and their capabilities. In the selection process that comes after the discovery and decision stages, the operator / Internet Service Provider (ISP) deemed optimal by the decision stage is selected. The selection stage is also concerned with the selection of Network Access Identifier (NAI) for Authentication Authorization Accounting (AAA) routing and network access authentication along with the final payload routing and possible session continuity issues.

In this thesis, we restrict our scope just to the decision stage of the network selection. More effort was spent to achieve a good level of user satisfaction by making the entire selection process automatic based on the user's current application requirements, velocity, location and preference policies. We were concerned about how to effectively utilize various hints that could lead to a better decision method.

Effort was also put to integrate the proposed decision model with existing technologies and provide a framework so that the entire concept can take form. The objective was to propose a new decision method, with higher levels of scalability and flexibility that works in a novel business model termed Heterogeneous Wireless Service Provider (HWSP) with improved user experience as the goal.

1.3 Solution Overview

In this research effort, it was observed that by maintaining the decision intelligence both at the ME and Network side we can have better access to the resources maintained at these places. This along with the using user's current velocity and application QoS requirements provides a novel way to select the optimal network for the user at any point in time.

In the proposed solution, in order to select the best possible interface, the handoff decision algorithm is split into two different parts. They are the Embedded Decision Algorithm (EDA), which is embedded in the ME side, and the Remote Decision Algorithm (RDA), maintained in the Heterogeneous Wireless Service Provider's (HWSP) network side. The HWSP could have service level agreements with various access networks and work in conjunction with a Location Information Server (LIS).

The decision to use one of the two decision algorithms is made based on the current velocity of the ME. If the current velocity is more than a certain velocity threshold, it uses the RDA at the HWSP. This is because in the case of fast moving mobile users, they can be better served by the HWSP with the help of the LIS. If the ME's velocity is found to be below the threshold, the decision will be made using EDA at the ME side.

Both algorithms also have a policy repository and policy enforcer, which work together in blocking specific networks and act as a first stage elimination point for non-optimal networks. In the second stage of the network selection procedure, the decision tables are filled with the parameters of the networks that have passed the policy enforcer and then a Cost-Utility function is applied to them. The Cost-Utility function works in such a way as to maximize the utility and minimize cost.

In order to ensure that the networks are selected based on the user's current application's QoS requirement; each application supported by the ME is assigned a fixed weight for its cost and utility values. The assigned weights reflect the user's particular requirements that are to be met, set during the user subscription period from a completed customer questionnaire. By using this fixed weight, the final selection will conform to the user's current application's demands. Thus the final network decision made will be based on that particular user's speed, location, QoS demands and preference policies.

1.4 Validation and Analysis Overview

To validate the proposed solution qualitatively, it is applied to a scenario that simulates a typical day in the life of a researcher working for a tech company. The solution's performance in deciding from a set of probable access networks was quantitatively evaluated by simulating it in Network Simulator-2 (ns-2) and comparing the findings with that of the conventional Radio Signal Strength (RSS) based handoff technique and methods using Cost-Utility calculations in similar conditions. Based on the evaluation and analysis of the proposed solution's capabilities and limitations, a group of environments that could benefit from the model was explored. During the validation process the solutions limitations were also investigated and needed future modification noted.

1.5 Structure of the Thesis

There are six chapters included in this thesis report. Chapter 1 gave the overview of the thesis. In chapter 2 the background for the thesis and the technologies involved are explored. Chapter 3 discusses the main motivating factors that lead to this research effort and details the problem along with a survey of existing solutions. Chapter 4 provides details of the proposed algorithm, its specification and a framework that it can work on. Chapter 5 presents a validation of the proposed algorithm using both qualitative and quantitative methods and draws conclusions and future work needed, which are further documented in chapter 6.

Chapter 2

Background

This chapter gives a brief background about the technologies and their functions discussed in this report. The first section of this chapter provides a generation-wise evolution of the mobile cellular systems. This section also explains briefly about other technologies that are deemed relevant to this study. The other two sections give background details of wireless handoff and positioning techniques, whose understanding is vital to the comprehension of this thesis effort.

2.1 Evolution of Mobile Cellular Technologies

It was understood from the beginning that the cellular system is an evolutionary structure, one that develops and expands to meet observed requirements [WEL84]. From the first cellular wireless system proposals made to the Federal Communications Commission (FCC) by American Telephone & Telegraph Company (AT&T) in 1968 to the present working 3G wireless systems, the design procedures and technologies have evolved considerably to cope with the demands in capacity and functions. A generation-wise evolution of the cellular wireless system is given below. Effort has been made to include other wireless systems that are relevant, but which do not necessarily fall into the cellular wireless system category.

2.1.1 First-Generation (1G)

The First-Generation Mobile Systems were the earliest cellular networks to be developed. The launch of commercial cellular networks around the world was led by Nippon Telegraph & Telephone Corporation (NTT) in Japan in the year 1979, followed by Nordic Mobile Telephone (NMT) systems in Scandinavian countries in 1981. Later, in 1985 Total Access Communications System (TACS) began operations in the United Kingdom [TOH02].

First-generation mobile communication systems were based on analog transmission techniques. These systems transmitted voice information using a form of Analog Modulation. Analog cellular systems primarily provide voice and low-speed data communication services over a certain geographic area. These cellular systems used two types of radio channels, control and voice channels. Control channels were used to retrieve system control information and compete for access. Voice channels were primarily used to transfer voice information. However, voice channels were also capable of sending and receiving some digital control messages to make necessary frequency and power changes during a call [BDF$^+$08].

In the case of Advanced Mobile Phone System (AMPS), the American system first deployed in 1983 in Chicago, a total of 40MHz of spectrum was allocated from the 800 MHz approved by the FCC. It offered 832 channels each to be used by a particular caller; with the rate of 10 kilobits per second (kbps). Traffic was multiplexed on to a Frequency Division Multiple Access (FDMA) system [TOH02]. The AMPS system supported frequency re-use and had a 7-cell reuse pattern. It also used handoffs to provide service continuity to mobile users. The lack of adaptability to the Second generation mobile systems and their inherent drawback such as poor security and limited system capacity lead to the ultimate demise of the 1G mobile systems.

2.1.2 Second-Generation (2G)

The Second generation, 2G cellular telecoms networks were first commercially deployed in Finland in 1991. The 2G services are also referred to as Personal

Communications Service, or PCS, in North America. The 2G systems were fully digital and used digital multiple access technologies such as Time Division Multiple Access (TDMA) and CDMA. The main 2G systems were GSM, PDC (Personal Digital Cellular), Integrated Digital Enhanced Network (iDEN), IS-136 (Interim Standard-136) or D-AMPS (Digital AMPS), which used TDMA for multiplexing and IS-95 or CDMAOne that used CDMA. The new design had the following advantages over existing 1G technologies: efficient spectrum allocation, better system security through digital encryption, new data services and room for standardization and interoperability between different manufacturers [TOH02]. 2G networks are still in use in many parts of the world. While first-generation systems supported primarily voice traffic, second-generation systems supported voice, paging, data, and fax services with different levels of encryption and security [TOH02].

2.1.3 Packet Digital Cellular Systems (Generation 2.5)

One of the key attributes of 2.5G mobile systems was the ability to transmit information (voice or data) broken into packets. Each of these packets is then routed by the network between different destinations based on addressing data within each packet [TOH02]. To obtain packet transmitting capability, mobile devices and Base Stations were modified to include new packet-switching equipment and protocols. In other words, 2.5G enable high-speed data rates over upgraded existing 2G networks, with small changes to the network hardware and software.

General Packet Radio Service (GPRS), a radio technology for GSM networks, is the one of the most important 2G systems. It promises shorter setup time for ISP connections and the possibility to charge by the amount of data sent, rather than connection time, thus bringing a paradigm shift in mobile billing.

Some recent protocols even build on existing GPRS and CDMA techniques to improve their data rate with much success. These new protocols include Enhanced Data rate for GSM Evolution (EDGE) and CDMA2000 1x-RTT (Radio Transmission Technology). The EDGE allows GSM operators to use existing GSM radio bands to offer wireless multimedia IP (Internet Protocol) based services at a theoretical maximum speeds of 384 kbps with a bit-rate of 48 kbps per timeslot and up to 69.2 kbps per timeslot in good radio conditions [TOH02]. These protocols made it possible for the network operators to provide 3G like data rates, with very little new investment.

2.1.4 Third-Generation (3G)

In its 3G standardization effort termed International Mobile Telecommunications 2000 initiative (IMT-2000), the ITU states that the 3G services were scheduled to be initiated around the year 2000. But, other than in Japan and South Korea, the implementation of 3G has been slower than anticipated. The main reasons for the slow adoption of 3G in the rest of the world include the high cost associated with the upgrading of existing equipment and licensing fees for additional spectrum. But, in Japan, the majority of customers were using 3G by the end of 2006. The five 3G interface standards approved by ITU along with their alternative names, are given below:

—IMT-DS (CDMA Direct Spread) also called UMTS, WCDMA
—IMT-MC (CDMA Multi-Carrier) also called cdma2000
—IMT-TC (CDMA Time-Code) also called CDMA TDD, TD-SCDMA
—IMT-SC (TDMA Single Carrier) also called UWC-136, EDGE
—IMT-FT (FDMA/TDMA Frequency-Time)

Key features of 3G systems include a high degree of commonality of design worldwide, compatibility of services, use of small pocket terminals with worldwide roaming capability, Internet and other multimedia applications, and a wide range of services and terminals [HHK06]. The 3G promised a maximum broadband access up to 2 Mbps and minimum of 144 kilobits per second (kbps) in high mobility traffic. It supported multimedia applications with capabilities such as fixed and variable rate bit traffic, asymmetric data rates and multimedia mail store and forward. The 3G networks promise a greater degree of security than their 2G predecessors. It uses the KASUMI or A5/3 block crypto instead of the older A5/1 stream cipher. Later researchers have identified a number of weaknesses in using KASUMI [BDK05].

In the ITU's IMT-2000 3G standardization project, the 3rd Generation Partnership Project (3GPP) committee worked on the evolution of GSM system and

3GPP2 concentrated their effort on non-GSM systems such as CDMAOne. Since their inception the two groups have made steady progress and at some point they were supposed to converge. Instead of converging three additional groups: Institute of Electrical and Electronics Engineers (IEEE) 802.16, IEEE 802.20 and CCSA (China Communication Standards Association) got involved to study the evolution of mobile wireless broadband making the picture more complex [TOH02].

In the near future, another intermediate generation termed 3.5G is expected to be available. The 3G-LTE (3G-Long Term Evolution), EV-DO (Release C), IEEE 802.16e and the revamped IEEE 802.20 are the four major technologies that are being developed to be used in future 3.5 G systems [BDF$^+$08]. All of above mentioned 3.5 G technologies use OFDM (Orthogonal Frequency Division Multiplexing) digital modulation scheme for achieving multiple access.

2.1.5 Fourth-Generation

The next evolutionary stage in wireless networks after 3G is called "Beyond 3G" or 4G. ITU prefers to call it "beyond IMT-2000".

Proponents of 4G believe that the deployment of 4G networks could happen roughly in the 2012–2015 time scale. Even though 4G is still mostly undefined, it provides promising aspects of convergence and seamless connectivity of different access technologies on an "Anytime, Anywhere" basis. The growth of 4G is predicted to drive down cost for access. However, the telecommunication industry does not look too keen to make a rapid push towards 4G until they make a good return of investment from the existing 2G/3G networks. Even the ITU does not seem eager to plan for the "beyond IMT2000" or 4G. Some industry experts think this is to give the mobile service providers time to deploy 3G services or to allow 3G to fully mature.

One of the characteristics of 4G will likely be an even greater global compatibility, giving users and information devices the capability to roam across a variety of heterogeneous network environments, to operate in various frequency bands, and to use a variety of air interface standards to optimize the use of spectral resources [HHK06].

4G is thought to be able to provide between 100 Mbps and 1 gigabit per second (gbps) speeds both indoors and outdoors, with premium quality and high security [KP06]. These systems would employ new modulation techniques, intelligent antennas, pico-radios, multi-user detection, reconfigurable self-healing networks, video-on-demand, higher speed Internet access, large file transfers, and other emerging applications and techniques [BDF+08]. Some manufacturers are even checking the viability of using a universal radio that automatically changes frequency channels and adapts to different air interfaces based on the communication link.

2.2 WiMAX

WiMAX specifications are created by the WiMAX forum. They are based on the IEEE 802.16 standard and were developed to deliver non-line-of-sight (LoS) connectivity between a subscriber station and base station with typical cell radius of three to ten kilometers. WiMAX has the capacity to deliver up to 40 Mbps per channel and provide up to 15 Mbps of capacity within a typical cell radius of up to three kilometers [WIM+06]. WiMAX technology already has been incorporated in laptop computers and smart phones to deliver high speed mobile Internet services.

IEEE 802.16 Working Group (WG) standardized IEEE 802.16d (also known as IEEE 802.16-2004) and IEEE 802.16e-2005. The IEEE 802.16d standard specifies a common air interface for fixed microwave equipment. The IEEE 802.16e-2005 is a mobile broad band specification and uses Orthogonal Frequency Division Multiple Access (OFDMA) technology. The OFDMA is an improved version of OFDM (Orthogonal Frequency Division Multiplexing). OFDM is a digital encoding and modulation technology used to achieve high data rate by using multiple overlapping carrier signals [AGM07].

The WiMAX forum claims that WiMAX has the capability to fill the existing gaps in the wireless broadband converge and also co-exist with the present and future cellular networks. There have been many efforts to integrate WiMAX and cellular networks [WIM06] [NFA06]. Using of WiMAX networks to address "last mile" broadband access has been highly successful in the last few years and observers believe that it will have a bigger role to play to make ubiquitous wireless broadband a reality.

2.3 WLAN

WLAN is the wireless version of the Local Area Networking (LAN) technology, designed to provide in-building broadband wireless coverage. It is based on the IEEE 802.11 family of standards. To support interoperability and compatibility, most WLAN vendors and providers adhere to the guidelines set by the Wi-Fi Alliance [WIFI]. The IEEE 802.11 standards family includes 802.11a, 802.11b, 802.11g, and 802.11n standards.

Among these standards, the most recent one, the IEEE 802.11n is expected to be finalized sometime after June 2010· Even though the standardization process of IEEE 802.11n is not yet finalized, there are many "Draft N" products are already available in the market. These products have significantly improved network throughput and range over products developed using older standards. New improvements in IEEE 802.11n such as using multiple-antenna spatial multiplexing technology (Multiple-Input Multiple-Output MIMO), Channel-bonding and frame aggregation help support a minimum throughput of 100Mbps. The Enhanced Wireless Consortium (EWC) was formed to help accelerate the IEEE 802.11n development process and promote a technology specification for interoperability of next-generation wireless local area networking (WLAN) products [EWC].

The WLAN systems were successfully deployed in hotspots, city centers, universities, airports, and underserved areas. WLAN systems typically provide a coverage range of about 1,000 feet from the access point and thus they are not the best choice for large-scale ubiquitous deployment. The deployment of WLANs will overlap other wireless systems such as WiMAX. See figure 1 for a representation of overlapping WLAN, WiMAX and Cellular networks [WIM$^+$06].

Today WLAN is considered as a tremendous success. A wide array of devices supports WLAN technology. A majority of laptops shipped today have a built-in Wi-Fi interface. Other devices including Personal Data Assistants (PDAs), cellular phones, cameras, media players and eBooks readers also sport WLAN interface technology.

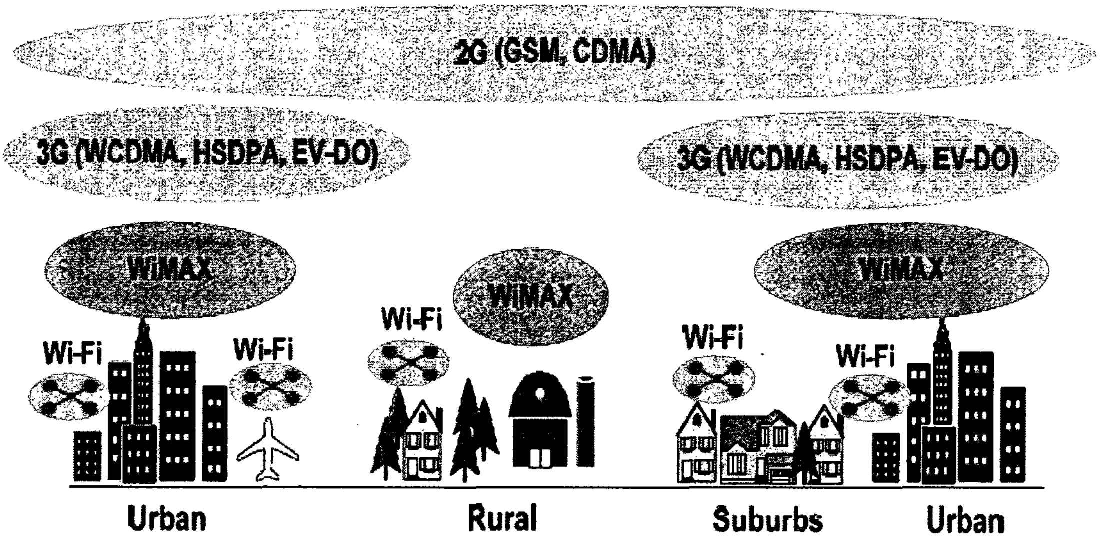


Figure 1: 2G, 3G, WiMAX and Wi-Fi coverage Source WiMAX Forum

2.4 Handoffs

A major change in the cellular system design as it evolved was the conversion from ideal, uniform hexagonal layout of cells to a wide variety of cell sizes and shapes, representing the actual coverage area in the real world [WEL84]. As more data became available from the field tests done by AT&T, Bell Telephone Laboratories (BTL) and Motorola in the second half of the 1970's, it became evident that in order to accommodate a greater number of subscribers in a given coverage area and reduce the transmission power the design should employ the "frequency reuse" concept [WEL84]. In frequency reuse, instead of having a cell that covers a larger area and supported by a single transmitter, many cells occupying smaller coverage areas were employed. This allowed the reuse of frequency without interference.

As the size of the cells became smaller to facilitate frequency reuse and later, to service areas with higher concentration of users, the need to hand off the mobile user's connection from one cell to another became more pronounced. A conventional handoff is used to change the ME's connection point to the core network from one Base Station (BS) or Access Point (AP) to another [POL96]. In other words, a user must be handed off into another cell before conditions in the cell he is using reach an unacceptable interference or signal level condition. A handoff is often initiated when crossing a cell boundary and the quality of the signal from the current base station or AP deteriorates. It is understood that well designed handoff schemes are essential to provide uninterrupted connectivity and load balancing and to meet specialized QoS demands of users [WEL84].

In the following section the important types of handoffs are explored. They are classified based on the layers they work on and other factor such as types of connections, frequencies and technologies they operate with.

2.4.1 Layer based Handoffs

L2 Handoffs:

L2 handoffs are used while roaming between Access Points (APs) inside ME's Home Network or within a network with the same Extended Service Set (ESS).

L3 Handoffs:

Handoffs that occur when the ME roams between APs of different IP networks or between APs in different ESS are called L3 handoffs. L3 signaling is needed to enable routing of IP datagrams to their current foreign location in the case of the L3 handoffs [PKH$^+$00]. In the case of L3 handoffs the ME's ongoing sessions are disrupted and connectivity through its home IP address is lost.

2.4.2 Connection based Handoffs

Hard Handoffs:

Hard handoff was used in older mobile systems such as AMPS, GSM without macro-diversity, Digital Enhanced Cordless Telecommunications (DECT) and D-AMPS. In these systems the ME always communicates with only one BS at any given time and the old radio link is always broken before the new radio link is established. The main drawback of this approach is that a call would be forced to be terminated if the network fails to set up a new voice path before the old radio link is disconnected.

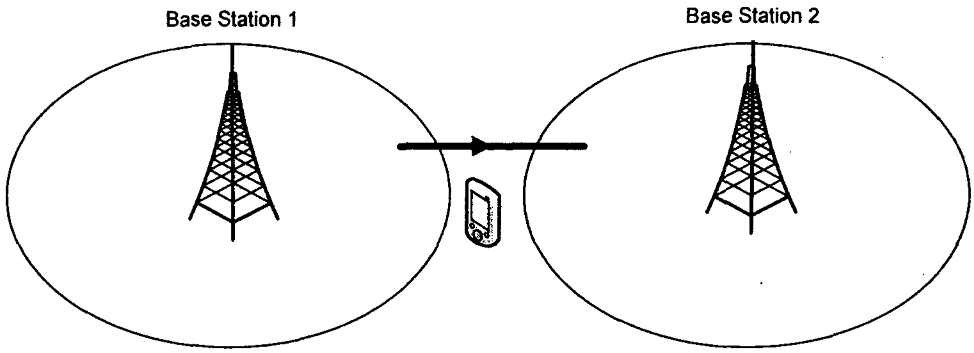


Figure 2 : Hard Handoff

Soft Handoffs:

In soft handoff systems such as CDMA, instead of using just one radio link, multiple radio links are used to communicate with Base Stations at any given time. During Handoff the signaling and voice information from multiple Base Stations are typically combined at the Mobile Switching Centre. A handset in soft handoffs may connect up to 2 or 3 radio links at the same time. This redundancy, while sacrificing some link availability, is maintained so that if one radio link fails the handset always has other links to stay connected [PKH$^+$00]. Therefore the soft handoff is less time critical when compared with the hard handoff.

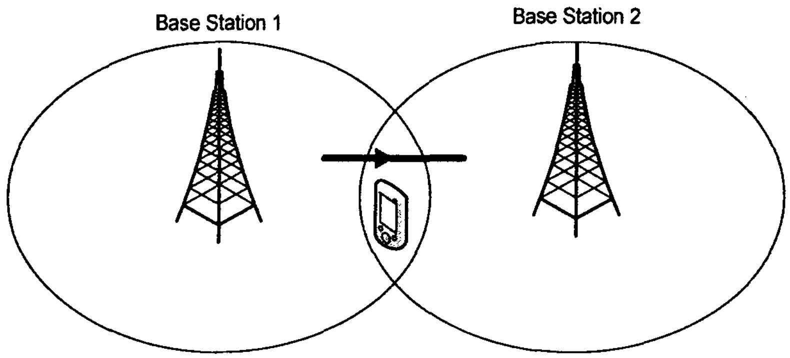


Figure 3: Soft Handoff

Softer Handoffs:

Softer handoff is a type of soft handoff, used in systems like Node-B in UMTS, where handoff occurs between two sectors of the same cell or Base Station. Softer handoffs are useful in cases where cells are divided into sectors and each Base Station serves several sectors of a cell [PKH$^+$00].

2.4.3 Decision Point based Handoffs

Network Centric Handoffs:

The Network Centric Handoff is the first type of the decision point based handoff, which classifies the handoff based on where the decision to hand off takes place. In network centric handoffs, which were used in first-generation analogue systems such as AMPS, the decision to switch to a new cell's Base Station is made by the network alone. As the delay constraints in purely Network centric handoff were high, they are no longer employed in advanced systems [MAL07].

Mobile Assisted Handoffs:

The Mobile Assisted Handoff works in a more distributed way when compared to the Network Centric Handoff approach. Based on the measurements taken by the ME the Mobile Switching Centre (MSC) makes decision to handoff. There are improvements in the overall handoff delay by using Mobile Assisted Handoffs instead of Network centric Handoff [PKH$^+$00], and thus more this approach is commonly used in advanced systems.

2.4.4 Technology based Handoffs

Horizontal Handoffs:

In Horizontal handoff there is no change in the network interface used to connect to the access network (see figure 4). In other words, in these handoffs, the MN switches between Base Stations supporting the same technology. Generally it is referred to as the Intra-Access Network handoffs.

Vertical Handoffs:

Vertical handoffs are characterized by a change in the network interface used to connect to the access network. In vertical handoffs, the ME moves across heterogeneous access networks that uses different access technologies. They are generally referred to as Intra-Access Network handoffs. Their main concern here is to maintain the ongoing service although there are underlying changes that affect IP addresses, network interface and QoS characteristics (see figure 4).

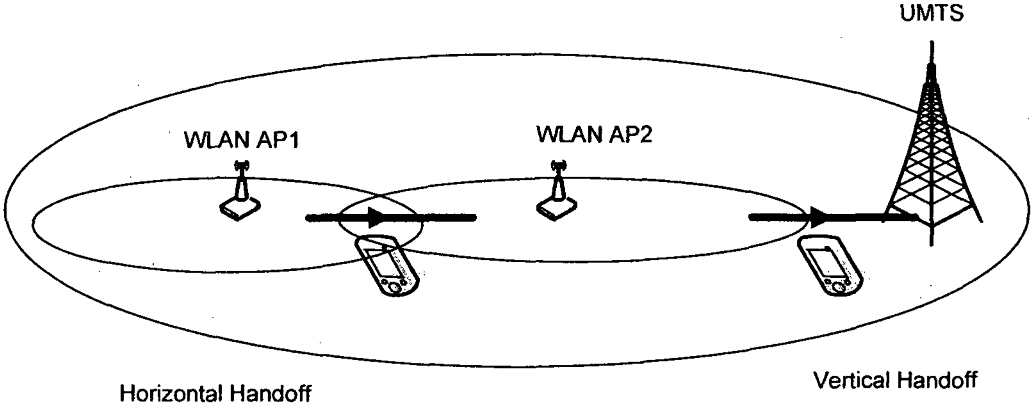


Figure 4: Horizontal and Vertical Handoffs

It is noted that the proposed handoff mechanisms for horizontal handoffs could not directly be used for vertical handoff. This is because the proposed handoff mechanisms for horizontal handoffs can only deal with the change in IP address and they are not designed to maintain ongoing service when network interfaces or QoS characteristics are changed.

To support vertical handoffs a number of new solutions and changes to the legacy Mobile IP [PER02] are proposed in the literature [SK97], [SBD$^+$04]. The vertical handoff is further divided into two types; they are Downward Handoff and Upward Handoff.

The Downward Handoff, typically initiated for performance optimization reasons, is characterized by a handoff from a large network cell with low data rates to a smaller network cell with higher data rates. An example of a downward handoff is the handoff from a UMTS system to WLAN.

An upward handoff is initiated usually to maintain connectivity to mobile users and is perceived to be more delay sensitive. It involves a handoff from a small network cell with high data rate to a larger network cell with lower data rate. A handoff from a WLAN system to an UMTS network is an example for upward handoff.

2.5 Positioning and Location Based Services

According to [VJ09] the mobile industry considers Location Based Services (LBS) as one of their new key features and has spent large amounts of money in developing technologies and acquiring business that would let them provide advanced LBS. It is thought that concerns over security and privacy, combined with the lack of compelling applications, are responsible for the poor market penetration of LBS today [VJ09].

The first mobile LBS project was the United States of America (USA) Department of Defense's (DoD) NAVSTAR-Global Positioning Systems (GPS) project that began in the early 1970's. The mandatory requirement of the FCC to have GPS chips in all mobile devices in USA to provide e911 service went a long way in making the LBS pervasive. The e911 directive needs the mobile phone networks to be able to locate the user in case of emergencies. The Canadian Radio-television Telecommunications Commission (CRTC) in Canada has a similar mandate to have all the cellular network providers e911 complaint by February 2010.

The increased demand for LBS led 3GPP to standardize them and they are described over three stages in [3GPP1], [3GPP2], and [3GPP3]. They are referred to as Location Services (LCS) and are made available for the following four clients: Emergency Services clients, Lawful Intercept clients, Public Land Mobile Network (PLMN) Operator clients and Value-Added Services clients.

Most LBS systems work by triangulation of signals to determine the distance and direction from the signal sources. Based on the type of signal source used they can be broadly classified into GPS, Cellular and Wi-Fi. In Cellular and Wi-Fi triangulation the signal source are cellular towers and Wi-Fi APs respectively. The GPS systems use high frequency signals from satellites to find the location. Very often combining two or more LBS techniques helps to reduce the delay involved. Most devices that are used to access the LBS applications do not have enough processing power to determine their own location. So, often devices that support LBS need Location Information Servers (LIS) to assist them with the calculating and transmitting back the needed information by any available link.

A LIS is also sometimes referred to as a Mobile Geographical Information System (MGIS). The CELLO group in [MGI01] specifies their design of MGIS for cellular systems. The LIS usually has a RAN map to mark the areas with RAN coverage. The RAN maps in the LIS also provide major QoS parameters of the represented RANs. The LIS can obtain and update this information by using mobile reporting as in cellular networks or by having SLA's with the various network providers. Various representation of the LIS are mentioned in the literature. Among them, [PP03] explores the potential of LIS, by utilizing it to avoid scanning procedures. It also objectively concludes that localized estimations and inherent imprecision does not disqualify the use of LIS for location based handoff decision support. [PP03] concludes that LIS is sufficiently safe and reliable to be used in real situations. Other works such as [SAL04] [MPK04] [[IMM$^+$03] [PP03] also assume the use of some LIS-like servers to perform better handoffs and claim their benefits to include reducing signaling traffic, avoiding dropped calls, increasing speech quality and providing mechanisms for resource allocation and planning [MPK04] .

The knowledge of the location of the MN at specific intervals can be used to calculate the speed and direction of the MN. Applying the velocity details of MN on the RAN map could help predict the time the MN will spend in a particular RAN. This information can be vital in making good handoff decisions. Some location based handoff efforts such as [PP03] [MPK04] use location information to calculate the user's predicted path length and time spent in a particular network and make decisions on when to hand off and if handoffs are necessary at all. Researchers agree that since the performance of LIS heavily depends on the accuracy of the prediction of the user's movement, advanced prediction methods should be researched intensively.

Chapter 3

Motivation

3.1 Problem Development

3.1.1 Seamless Connectivity

The ability to roam across different heterogeneous network environments and use a variety of air interfaces in a seamless manner is thought to be the most salient of the proposed characteristics of future 4G networks. Achieving this goal of seamless mobility is crucial because it is understood that a single wireless access technology alone will be incapable of meeting the various requirements on mobility, data rate, coverage, price and services in the future 4G era [IMM$^+$03].

Even though it is commonly agreed upon that seamless mobility should be an integral part of future wireless networks, it still has many open issues that are to be solved. The main challenges to seamless mobility stem from the inherent difference in mobility, QoS, authentication and authorization requirements of various access networks involved. Delays encountered in different stages such as discovery, decision, selection, authentication and configuration can affect the performance of the application in use. The various functionalities that are required to achieve seamless mobility in a heterogeneous network environment are: service continuity, application class, service quality, network discovery, selection, roaming support, authentication and authorization, billing, security and power management [BL07][BL06].

Achieving seamless mobility across heterogeneous access networks is agreed to be quite complex and is a topic of active research. The effort to integrate cellular networks with other access networks started with an endeavor to integrate GSM-WLAN networks in the early 1990's. Many such efforts followed, which tried to integrate various flavors of cellular networks with WLAN [SZC07] [BCH$^+$03] [KHP03] [VN05]. Work is also in progress under various working groups to standardize and optimize heterogeneous handoffs to achieve seamless mobility.

The 3GPP-WLAN interworking architecture [3GP04] proposed by the Third Generation Partnership Project (3GPP) aims to provide WLAN access to 3GPP subscribers. It defines ways to develop a network selection mechanism with AAA support using the ME's subscriber identity module (SIM). The 3GPP document also proposed postpaid and prepaid charging methods for its interworking architecture. The IP Mobility Optimizations (MobOpts) working group within the Internet Research Task Force (IRTF) has been working on ways to optimize seamless mobility by mainly looking into mechanisms for smooth handoffs and reducing re-authentication delays. The Internet Engineering Task Force-Detecting Network Attachment (IETF-DNA) working group is developing mechanisms for detecting and reconfiguring IP layer configuration faster and thereby reducing the overall delay involved. The IETF working group, Mobility for IP: Performance, Signaling and Handoff Optimization (MIPSHOP) is working on the network layer protocols to reduce packet loss by providing fast connectivity during handoff. It is concentrating its effort to publish extensions to Hierarchical Mobile IP versions 6 (HMIPV6) and Fast Handovers for Mobile IP versions 6 (FMIPV6) as proposed standards [K0005]. Two other IETF Working groups, Protocol for carrying Authentication for Network Access (PANA) [PANA] and Next Steps in Signaling (NSIS) [NSIS] work on enhancing the authentication and signaling functions in handoff by extending existing AAA infrastructure and Resource Reservation Protocol (RSVP) QoS signaling protocol respectively.

Even though much work has been done on the individual aspects of heterogeneous wireless systems, very few proposals exist for a complete architectural solution to make seamless mobility a reality. Among them [BL06] defines a common architectural solution to enable seamless connectivity by using an automatic network selection. Even though it adds two new logical functionalities at the network side to facilitate the monitoring and collection of standard set parameters, [BL06] does not provide a decision making algorithm to be used in this context. In order to identify all radio technologies in the signaling area "Multimedia Integrated network by Radio Access

Innovation" (MIRAI), advocates the use of a separate Basic Access Signaling (BAS) mechanism, which runs on existing radio technologies. MIRAI is one of the few papers that try to provide an architectural solution, with a proof-of-concept demonstration system. It was observed that implementing BAS on existing wireless systems or as a new dedicated wireless system requires considerable effort and is not practical [BL06].

The IEEE 802.21 group is working on a framework that uses a Media Independent Handover (MIH) function to achieve seamless mobility across heterogeneous access networks [IEE21]. It uses policies and uses lower layer triggers to obtain network information needed to perform handoffs. The group is also defining a framework to support information exchange to aid mobility decisions [BL07].

3.1.2 Network selection problem

For seamless connectivity to become a reality it is vital to have an efficient network selection and discovery scheme. It is crucial to solve the network selection problem because without the opportunity to switch to networks that are better or more capable, the user will not risk changing his point of attachment. This could render the entire seamless mobility concept useless. In this section we try to discuss in brief, the various parts of the network selection problem and explore existing solutions and relevant parameters to be considered in the implementation of its second phase, the decision phase.

The network selection can be broadly classified into three major parts: discovery, decision and selection. The discovery stage involves discovering available candidate access networks and their capabilities. Picking the most suitable network from an array of candidate access networks is done in the decision phase. In the final selection stage the operator/ISP deemed optimal by the decision stage is selected and the connection point of the user is changed (if necessary) by handoff. It is also concerned with the selection of Network Access Identifier (NAI) for authentication, AAA routing and network access authentication along with the final payload routing and session continuity issues [AAB08].

The network selection problem by itself represents a huge challenge and thus solving it requires breaking it down into the above mentioned parts. As mentioned before, in this thesis effort, we only deal with the decision phase of the network selection problem. In the decision phase, it is vital for the decision mechanism employed to come up with an optimal network because the ME's connection is essentially handed over to this network picked by the decision mechanism and the user's subsequent connectivity quality is also dependent on it. In a heterogeneous wireless environment the decision issue is more pronounced because of various reasons including difference in QoS provided by various access technologies; the fluctuating user demand and the inherent dynamic nature of the wireless link. Poorly designed mechanisms could reduce the quality of service (QoS) and generate unwanted signaling traffic and even lead to severe data interruptions [STO02] [HBN08] [OF09].

Different decision mechanisms to pick the most suitable network have been proposed in the technical literature. The early decision mechanisms were based on fuzzy logic inference techniques and conventional MADM (Multi Attribute Decision Making) methods. The fuzzy logic based algorithms [LCC95] [TRV99] used parameters such as Radio Signal Strength (RSS) and hysteresis values to pick the most suitable networks. [SJ05] and [SJ$^+$05] used MADM decision methods such as Analytic Hierarchy Process (AHP) and Grey Relational Analysis (GRA) to select the most suitable network by making tradeoffs among various decision factors. [OPM05] uses a Cost-Utility function based decision algorithm to try and select a network with the highest utility and lowest cost. Most of the proposed decision mechanisms were thought to be using limited decision factors in their calculations and to remedy this and represent the user requirements in a more dynamic way, the policy based decision approaches were introduced [YJK$^+$03] [BL07] [SZC07]. They based their decisions on explicit user defined rules or policies to capture and satisfy the user's demands. [SZC07] goes a step further in defining a policy framework to select optimal networks. It was observed that that the entire network selection process can be made more responsive if the location information of the user is also considered as a decision parameter.

Trials have confirmed that the knowledge of user's location along with coverage information and location of wireless network resources can optimize the network decision process [PP03] [MPK04]. The European Union-Information Society Technologies (EU-IST) project, Cellular network optimization based on mobile location

(CELLO) [CELLO] conducted location aided handover trials to establish the best way to use location information to optimize cellular network decisions. Efforts are in place to scale the trails results to include heterogeneous wireless networks. The CELLO project utilizes a Mobile Global Information System (MGIS) with feeds from Global Positioning System (GPS) for collecting location specific data from the network and ME [LKF$^+$01]. Even though many location based decision proposals exist for the cellular network, work is still going on to integrate it in the heterogeneous wireless environment. In a separate work, [MLG04] proposes the use of a Hybrid Information System (HIS) to reduce the time spent in scanning for candidate networks in the discovery stage but fails to provide any particular decision mechanism.

Similar to utilizing location information for better decisions, the use of user's velocity and direction (to predict the time that would be spent in a particular network's coverage area) has the potential to optimize the network decision process. While most proposals do not take the velocity of the user into consideration, CELLO has made provisions to calculate the user's velocity and direction and to use this information with location and coverage matrix in WLAN hotspots. In working with a Global Information System (GIS) [SPA03] proposes to use a Spatial Decision Support System (SDSS) to manipulate and do data analysis in order to search for optimal solutions. The authors claim that this effort can be extended to include telecommunication networks. Some proposals such as [LZ05] investigate the use of data mining methods to discover mobile patterns and provide decision schemes based on them. Even though the work done by the CELLO and other research efforts has made quite a few inroads into location based handoff utilization, extensive research is still needed to weed out possible errors in the various prediction mechanisms proposed and at the same time extend existing frameworks to include multiple access networks.

In the survey of the solutions to implement a decision mechanism for the network selection process it became evident that location information is vital to perform effective seamless handoffs. It was also found that policy information is quintessential to capture intricate user demands and represent user preferences. Most of the handoff schemes in the literature fail to consider the user velocity, even though this information can be strategically used to avoid unwanted and suboptimal network connections. The surveyed solutions disagree with the actual placement of decision intelligence.

Most of the surveyed solutions can be broadly classified into ME based or network assisted approaches. [LCC95] [TRV99] [OPM05] can be classified as ME based solutions and [SJ05] [YJK$^+$03] [BL07] [SZC07] use variations of the network assisted approach. Even though both approaches have their drawbacks, the network assisted approach is preferred by most recent proposals. The presence of QoS information stored centrally with in the operator network provides a challenge as well as an opportunity. Referring to this stored information may cause unwanted delay for decisions concerning stationary or slow moving users, whose network parameters do not change significantly. At the same time having fast having fast access to this information is vital for decisions involving fast moving users, whose network parameters change considerably with the increase in velocity. It would be efficient to have an approach where the decision process is neither ME based nor network assisted but one that requires the placement of decision intelligence at both the network (centrally) and at the ME (user equipment) side. The triggering of the decision process can be based on the user's current velocity.

There is a need for a comprehensive decision mechanism that is automatic and based on the user's current velocity, location and preference policies and QoS requirements. The lack of effective decision support is widely recognized as one of the most important and challenging problems that is impeding the implementation of seamless connectivity and solving it can go a long way in realizing the goal of seamless mobility.

3.1.3 HWSP Environment and Payment Scheme

There is currently a high demand for 'smart phones'—those that offer a higher set of capabilities than a typical mobile phone. Most smart phones have their own specialized Operating Systems and advanced application set. They usually contain more than one network interface. In 2007 these high-end devices represented around 10% of the global mobile phone market according to the analyst firm Canalys. This trend is only expected to rise. There is also a push towards more network services such as WiMAX, especially in the developing world. WiMAX Forum working group [MAXFO] predicts that over 800 million people will have access to next-generation WiMAX networks by 2010. Laptops with WiMAX interfaces are already in the market and many more vendors are seriously considering adding WiMAX interfaces as part of their standard equipment.

All this current access provider competition is predicted to eliminate traditional monopolies enjoyed by the access providers and a paradigm shift in the customer service provider relations is expected. Works such as [OPM05] and [ADK$^+$05] discuss the growth of heterogeneous access environments such as the Service Oriented Heterogeneous Wireless Network Environment (SOHWE).

Figure 5 represents the layout of a basic Heterogeneous Wireless Service Provider (HWSP) environment. The Heterogeneous Wireless Service Provider can be a network access provider (e.g., Cellular service provider) providing heterogeneous services or it can work as a single entity that provides standalone heterogeneous services. A user can subscribe to the HWSP to manage and provide his access connectivity. The presence of the HWSP plays a vital role in effectively conveying or transferring various hints that could lead to a better decision method, this is more so for users travelling with high velocity.

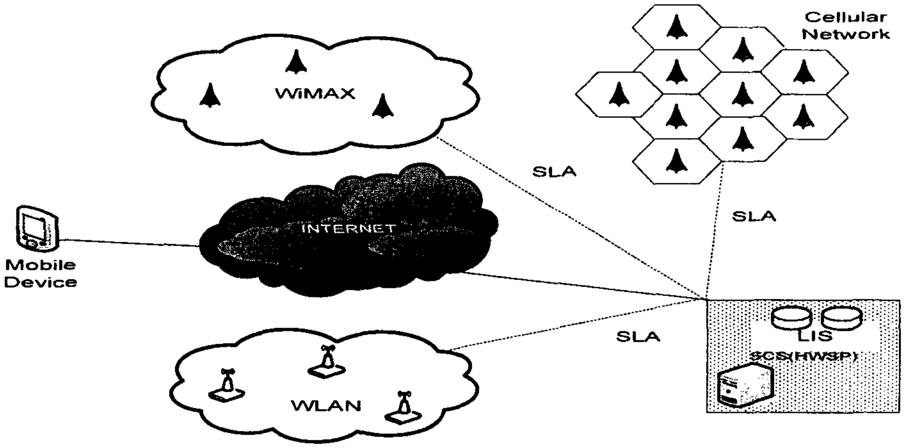


Figure 5: Heterogeneous Wireless Service Provider (HWSP) Environment

The driving force behind the push for seamless mobility has been the promise of mobile broadband internet and the demand for better services. The success of the seamless mobility concept is interlinked to development of provisions to extract and share profit generated by providing connectivity and services. Pricing issues in heterogeneous wireless environments are vital, yet challenging, because the strategies employed in conventional wireless systems do not hold true here. Researchers envision the future wireless heterogeneous environment as a system where service providers and users are no longer permanently attached to or loyal to any one network. Rather, mobile customers may 'shop around' for the 'best' available network for their particular application, in the current location at the current time [SJ05], [OPM05].

The authors of [JA02] believe that the content service market is imperfectly competitive. Factors observed in the ISP market for mobile broadband users also suggest that it is not perfectly competitive either. For example, a user connected to a 3G access network making a voice call on his ME does not always prefer to switch to a newly detected WLAN network, even though that latter network could provide a cheaper and better alternative.

There is a need to provide the users with automatic tools to search for the best prices and services. Also effort should be made to investigate schemes such as the dynamic pricing and batching [JA02] to learn customer behavior by experimentation and effectively utilize constrained resources [SAA+04]. The immense potential of the seamless connectivity market can be only realized if the users have access to decision mechanisms and applications that are adaptable to the dynamic characteristics of the radio environment and that also have intelligent inbuilt functions to aid the user to effectively 'shop around' and choose the most suitable Radio Access Network (RAN) [SAA+04]. In short, there is a need for a novel business model to realize the goal of seamless connectivity across heterogeneous access networks.

3.2 Proposed Solution

Considering the problems of existing solutions and the findings of related trials it was inferred that any effective network selection algorithm should include location, QoS, velocity and user policy parameters. It was also observed that instead of using the ME based or network assisted approach in placing the decision intelligence, if the decision intelligence were to be placed both at the network (centrally) and at the ME side (user equipment), and triggered based on users current velocity - a new level of efficiency can be achieved.

By concentrating the effort to devise an effective way to utilize the user's current velocity and pick the most suitable network at any time for the user, two new decision algorithms, Embedded Decision Algorithm (EDA) and Remote Decision Algorithm (RDA), are proposed. It was observed that the seamless connectivity market is monopolistic and in order to remedy this and share revenue between various players a new business model called Heterogeneous Wireless Service Provider (HSWP) is also proposed.

In the proposed solution, in order to select the best possible interface the handover decision algorithm is split into two different parts. They are Embedded Decision Algorithm (EDA), which is embedded in the ME side and the Remote Decision Algorithm (RDA), kept in the Heterogeneous Wireless Service Provider (HWSP). The HWSP could have Service Level Agreements (SLA) with various access networks and also work in conjunction with a Location Information Server (LIS). The decision to use one of the two decision algorithms is made based on the current velocity of the ME. If the current velocity is more than a certain threshold, the RDA at the HWSP is used. This is because in the case of fast moving mobile users they can be better served by the HWSP with the help of the LIS. If the mobile user's velocity is found to be below the threshold, the decision will be made using EDA at the ME side.

Both algorithms also have a policy repository and policy enforcer, which together work in blocking specific networks and act as a first stage elimination point for non-optimal networks. In the second stage of the network selection procedure the decision tables are filled with those networks parameters that have passed the policy enforcer filter and a Cost-Utility function is applied to them. The function works in such a way as to maximize the utility and minimize cost. In order to ensure that the networks are selected based on the user's current application's QoS requirement, each application supported by the ME is assigned a fixed weight for its cost and utility values. The assigned weights reflect the user's particular requirements that are to be met. By using this fixed weight the final selection will conform to the current application's demands. Thus, the final selection made will be based on that particular user's speed, location, QoS demands and preference policies.

Chapter 4

Design Description

4.1 Proposed Framework

In this section the major elements of the proposed framework, their components and interactions are explained. Mobile Multi-interface User Terminal (MMUT) and the Seamless Connection Server (SCS) form the two endpoints of the framework. As indicated before it is the placing of the decision intelligence at both these places that makes this framework unique, flexible and effective. Figure 6 shows the complete framework with all the elements.

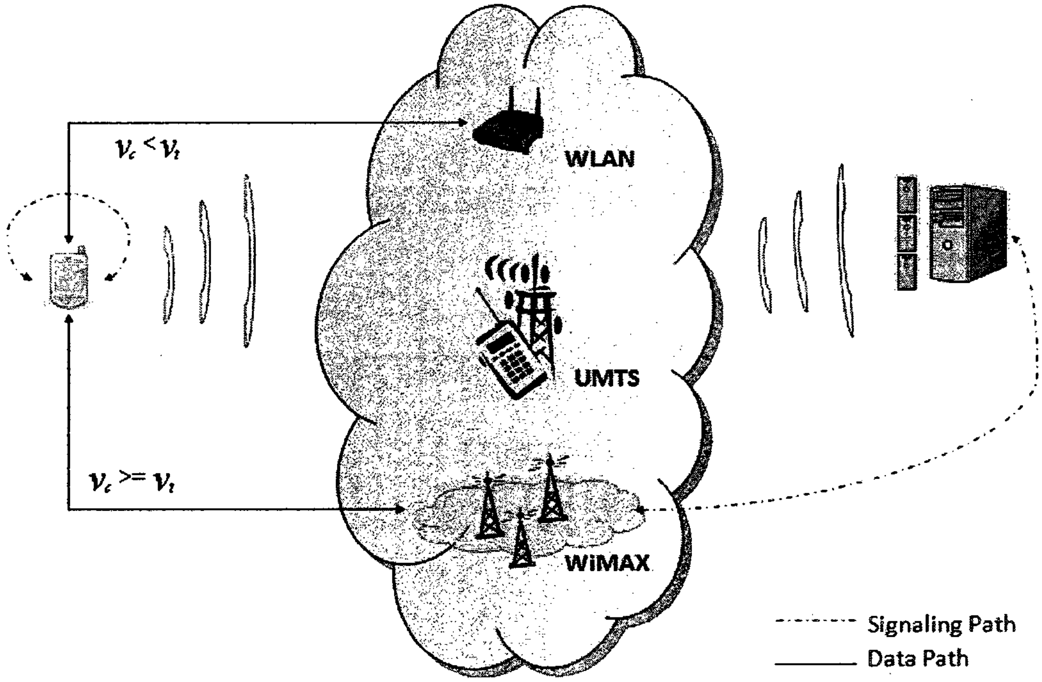


Figure 6: Elements of Seamless Connection Framework

4.1.1 Mobile Multi-interface User Terminal (MMUT)

The Mobile Multi-interface User Terminals (MMUT) is a user terminal equipped with multiple RAN modules or reconfigurable Software Defined Radio (SDR) in order to access different RANs. Devices that can handle both WLAN and cellular networks are already in the market and work to include more capabilities is in progress.

In our design of MMUT shown in figure 7, along with multiple RAN modules we have a Location Velocity Module (LVM) that can find the location and velocity of the MMUT at any given time. We have also included an event handler that can capture unexpected events and process triggers that might arise from the MMUT and the network. All the mobility management work is done by the mobility management module, which has a mobile IP client.

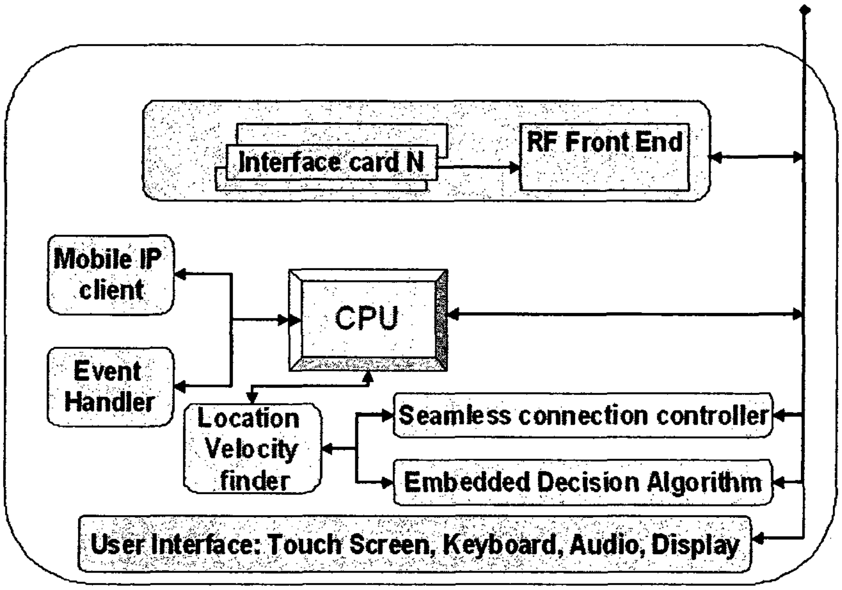


Figure 7: Mobile Multi-interface User Terminal (MMUT)

Connected to the LVM are the Seamless Connection Controller (SCC) and the Embedded Decision Algorithm (EDA) module. It is the SCC that decides whether the computation for the selection process should be done in the MMUT (at the EDA module) or sent to the SCS (at the network side). It is also responsible for the periodic refreshing of the data involved in the decision process to keep it up-to-date. The algorithms involved and the working of the SCC are detailed in section 4.2. The names MMUT and ME, both refer to the same user mobile device in this thesis effort.

4.1.2 Seamless Connection Server (SCS)

In this thesis effort both SCS and HWSP are conceptually one and the same thing. The SCS is the actual provider of heterogeneous wireless communication services. It can work with various network access or service providers through Service Level Agreements (SLA) and thus cater to all the user's data and service needs. The SCS or the Heterogeneous Wireless Service Provider (HWSP) can be a network access provider (e.g., Cellular service provider) providing heterogeneous services or it can work as a single entity that provides standalone heterogeneous services.

The benefit of providing the HWSP, the charter to establish and maintain stable unbiased service is twofold. First, having a single entity deal with all the connection and service logs helps to maintain a unified billing infrastructure. The second benefit is that since the HWSP holds Service Level Agreements with other content and connection providers it can obtain reduced and bargain prices for its customers. From a business point of view, it opens new avenues for the connection providers (especially the cellular providers) to have access to this new service provider market. The HWSP can also work towards maximizing existing resources, increasing the imperative to deploy more broadband service in places where it is needed and also at the same time maintain and ensure customer loyalty in future wireless networks where the users are more willing to 'shop around'.

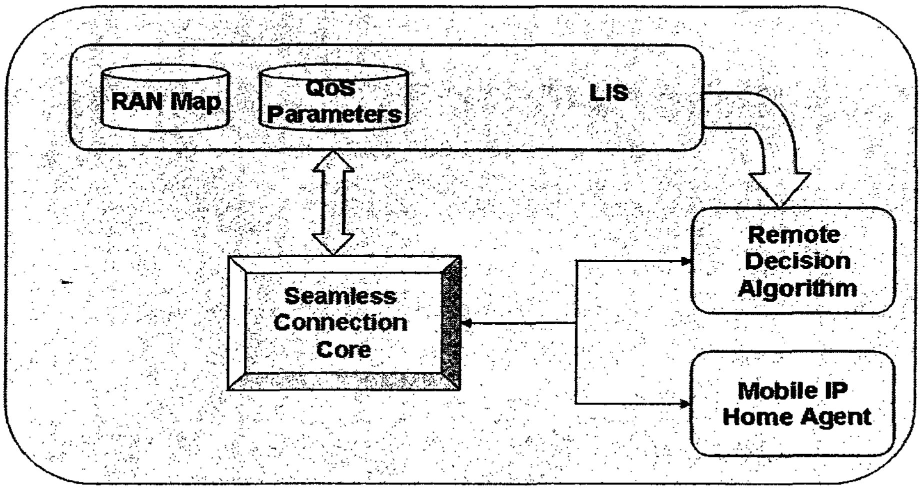


Figure 8: Seamless Connection Server (SCS)

The design of the SCS helps the decision algorithm module in it called the Remote Decision Algorithm (RDA) to make the best possible selection of resources even for users traveling at high velocities. This is achieved with the help of its Location Information Server (LIS) component. The LIS is connected to the seamless connection core and gives a bird's eye view of the user's connection possibilities by utilizing a RAN map (see figure 4.3). The SCS is also equipped with a Mobile IP Home Agent [PER02] to manage its mobility.

4.1.3 Working of the Framework

In [IMM$^+$03] the authors propose to use a Basic Access Network (BAN) to facilitate the network discovery, selection and handover. This wireless system reserved for signaling requires a broader coverage and might prove to be difficult to implement.

In our framework instead of using a single dedicated system, we choose any one viable network to make the initial communication with the SCS (only for users with higher velocity threshold). This viable network can be picked from a default list of connections in the SCC cache or by using an already established connection. The signaling is further reduced in the case of users with low velocity threshold as the entire decision process is completed in the ME and there is no need to communicate with the SCS. The flexibility of implementation allows the low-velocity users to check with the SCS to verify the connection decision made by the EDA and for billing reasons. This step is optional though.

When the user activates a particular application, the seamless connection controller in the ME compares the Current Velocity (ν_c), obtained from the LVM to the velocity threshold (ν_t) set by the HWSP. The SCC then picks the appropriate decision algorithm to make the best possible connection decision based on the comparison. After the decision is made a soft handover is used to transfer the data connection from the existing network to newly selected one. A new signaling path is also established with the SCS through the new network. The working of the respective algorithms is mentioned in section 4.2.

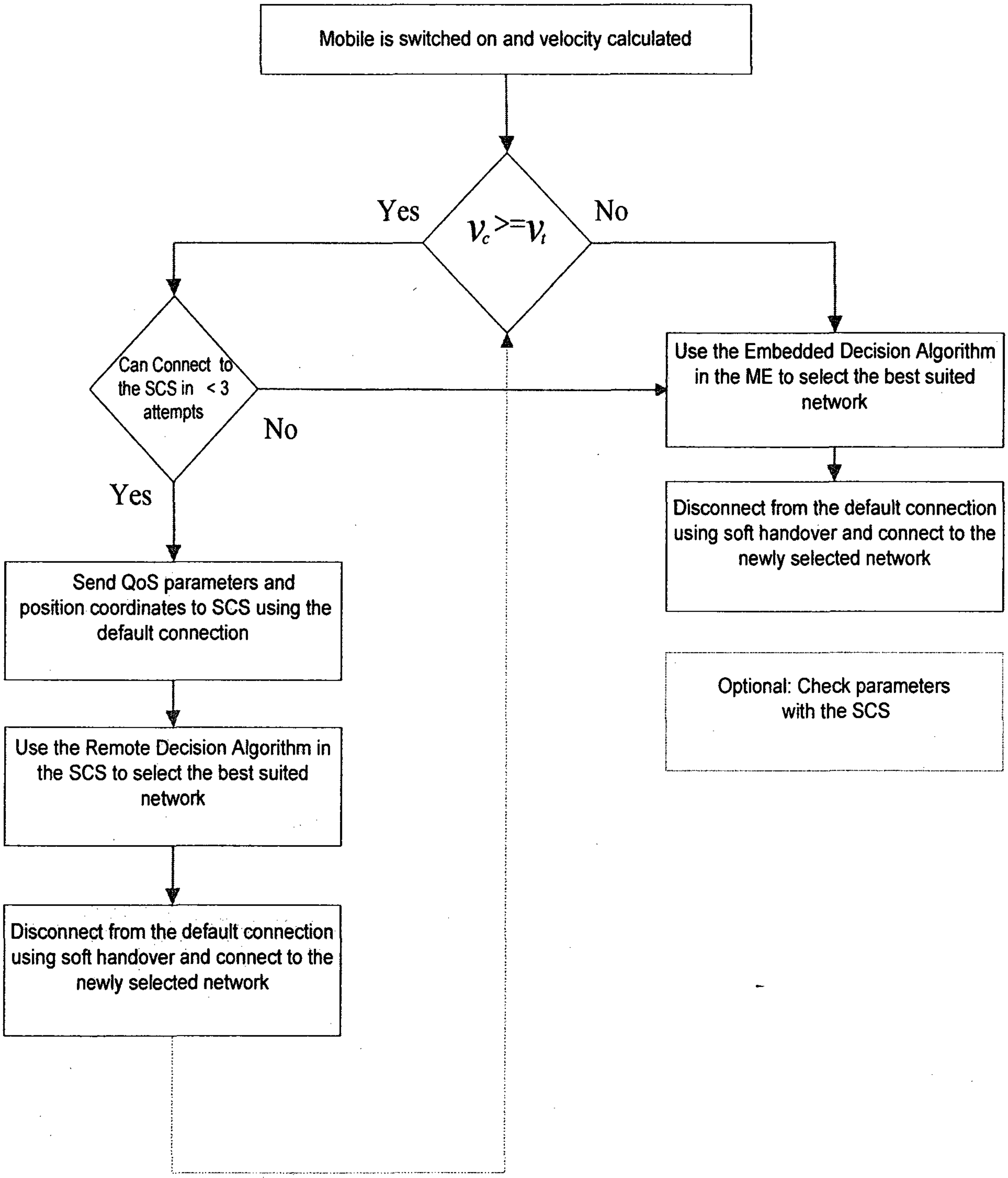


Figure 9: Decision Flow Chart

4.2 Proposed Algorithms

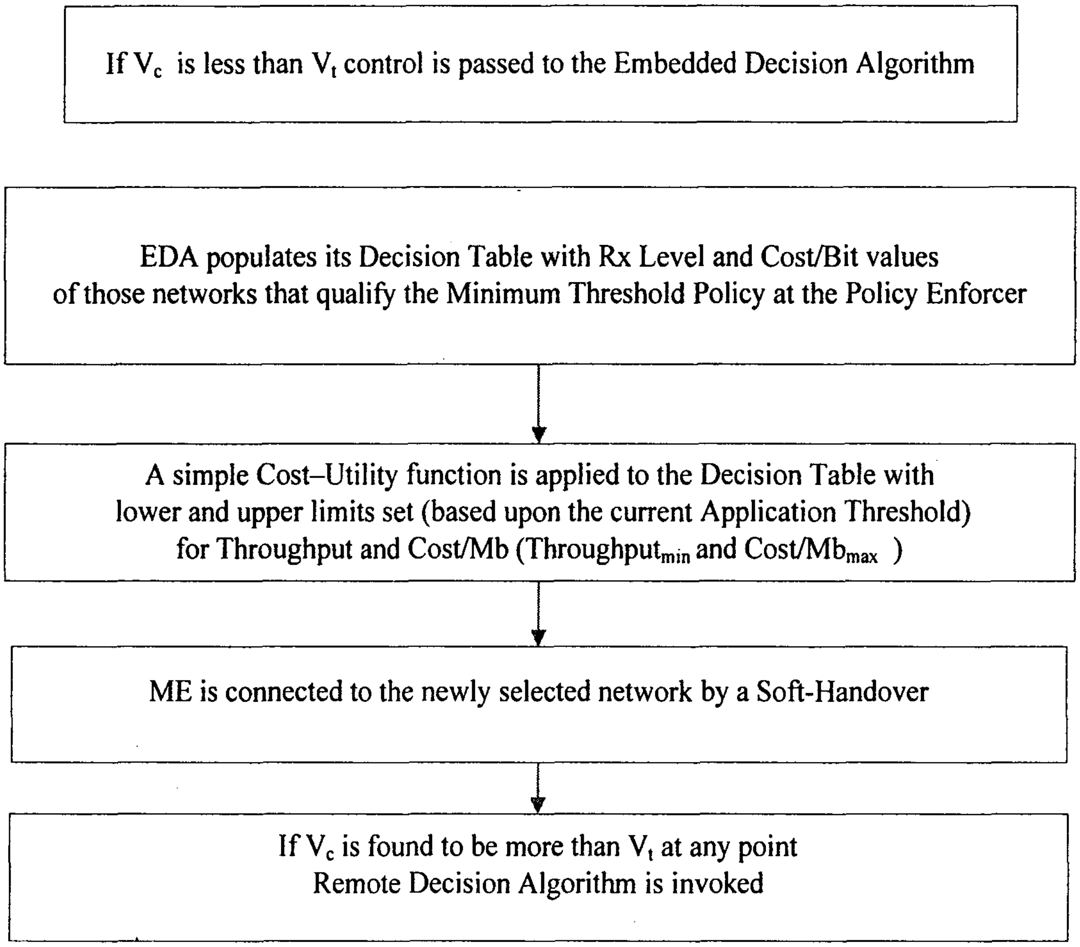
As mentioned before, it is the current velocity (v_c) that stipulates where the decision process should take place. The flow of control is explained by the flow chart in figure 4.4. If the v_c is found to be less than v_t (slow moving user) the control is passed to the EDA in the ME along with the selected application's ID. On the other hand, if v_c is found to be more than v_t (fast moving user) the control is moved along with the selected application ID, current location co-ordinates and QoS parameters to the RDA in the SCS using any viable network. If no viable connection is obtained to make the initial connection to SCS, the decision control is passed back to the SCC.

The SCC will then decide to use the EDA to complete the decision process, after a limited number of attempts. So, in cases where $v_c > v_t$ and no connection to the SCS can be established, they will be treated in the same way as a slow moving user. Both of the algorithms are explained in detail below. It is to be noted that while the RDA requires location information to function, the EDA does not.

4.2.1 Embedded Decision Algorithm (EDA)

The EDA working from the ME uses a simple Cost-Utility based function to select the best possible network to satisfy the user application requirements. This Cost-Utility function is applied on the EDA decision table that has Network ID, Throughput observed and Cost/Mb as the three fields. The Cost-Utility function is used to select a network with the minimum cost and maximum utility from the group.

The EDA decision table is filled with only those networks' information that satisfies the Minimum Entry Policy (MEP). The MEP, which is further explained in section 4.3.2, uses a policy enforcer to filter out all those networks to which the user might choose not to connect for some valid reason. This represents the first phase of the selection process. Each of the applications that the ME supports is given a minimum Throughput value ($Throughput_{Min}$) and maximum Cost/Mb value ($Cost / Mb_{Max}$) called the Application Threshold (AT). The Application Threshold is assigned to each application by the HWSP with inputs from the user (by filling a 'User Budget Questionnaire' at the time of subscription setup).



If V_c is less than V_t control is passed to the Embedded Decision Algorithm

EDA populates its Decision Table with Rx Level and Cost/Bit values of those networks that qualify the Minimum Threshold Policy at the Policy Enforcer

A simple Cost–Utility function is applied to the Decision Table with lower and upper limits set (based upon the current Application Threshold) for Throughput and Cost/Mb (Throughput_{min} and Cost/Mb_{max})

ME is connected to the newly selected network by a Soft-Handover

If V_c is found to be more than V_t at any point Remote Decision Algorithm is invoked

Figure 10: Embedded Decision Algorithm (EDA)

After the control and selected application's ID is passed from the SCC, the algorithm refers to the EDA decision table and the Cost-Utility function is applied. In this second phase the Cost-Utility function is applied only to those entries of the decision table that adhere to the selected applications range. Using this Application Threshold along with the Cost-Utility function makes sure that each user's specialized application demands are represented in the final decision process.

Section 5.1 provides a sample of the selection process in a given scenario. After the decision is made the connection is transferred to the new network by soft handover.

During the periodic checks, if the network's parameters are found to differ from the previous readings the entire process is repeated and the new decision is enforced with the approval of the SCC.

4.2.2 Remote Decision Algorithm (RDA)

The RDA, even though it works in a similar way as the EDA, also uses location information from the LIS to make the decision. Since the RDA is situated at the SCS along with the LIS, it is better equipped to serve the fast moving customers.

The RDA also maintains a decision table similar to the one used by the EDA, but the RDA table has one more field. The entire RDA decision table fields are Network ID, Throughput, Cost/Mb and time-out value. The new field, time-out value, is calculated and reported by the Time-out Calculation Module in the LIS.

As in the EDA, the decision tables are only populated with those network details that qualify according to the Minimum Threshold Policy. The application range for the RDA also includes a minimum time-out value, $Time\text{-}out_{Min}$ along with the minimum Throughput value and maximum Cost/Mb value. This minimum time-out range is included in the decision process to ensure that the network that is selected by the algorithm will not time out before the application can make a positive benefit from the connection.

After the control, current application's ID, current location co-ordinates (L_c), current velocity (V_c) and QoS parameters collected by the ME are passed from the SCC to SCS, the RDA refers to the decision table and the Cost-Utility function is applied on those entries of the decision table that follow the current application's range. The selected network will have minimum Cost/Mb and maximum Throughput and also have a time-out value more than the application's minimum timeout value.

After the decision is made the connection is transferred to the new network by soft handover. A new signaling path is also established between the SCS and the ME for sustaining the connection with the SCS through the new network. During the periodic checks explained in section 4.3.3, if the network's parameters are found to be changed the entire process is repeated and the new decision is enforced with the approval of the SCC.

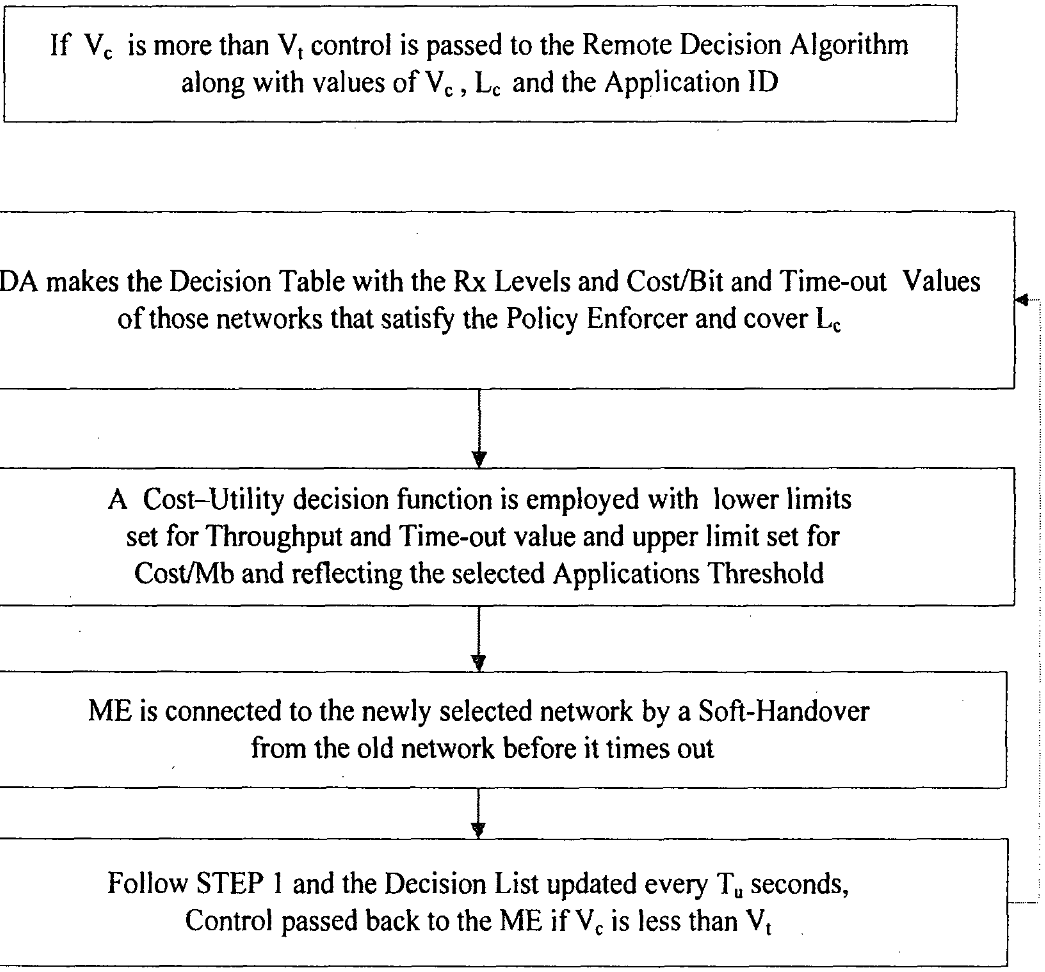


Figure 11: Remote Decision Algorithm (RDA)

There can be added provisions to supply the best three networks based on their ranking in the RDA algorithm to the ME, so even if connection to one of them cannot be established there are other options for the ME before contacting the SCS again or doing a full power intensive scan. This can be further extended by utilizing projected ME positions and making advanced decision and resource allocation based on that calculation. For the time being we are not concerned with that possibility.

4.3 Specification of Algorithms

4.3.1 Assumptions

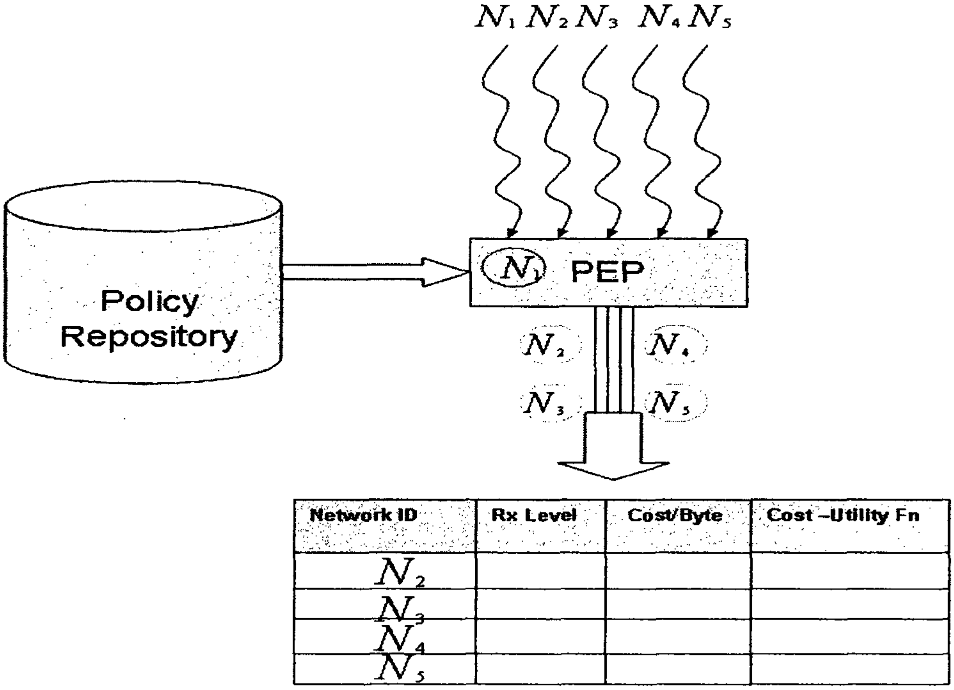
Certain assumptions are made during the design of the algorithm about their underlying mechanisms and computations. They are as follows.

- There are provisions inside the ME to find the location and velocity with good accuracy
- The ME can support multimode radio access without serious power consumption problems.
- There is availability of a RAN coverage footprint database [PP03] [IEE21] to support RDA queries.
- The calculation made by the Time-out Calculation Module is fairly accurate and correctly reported to the RDA.
- There are SLAs between various RAN service providers and the SCS represented by the HWSP, so that certain QoS information can be obtained from them. This information is stored in the QoS Parameter Indicator Module in the SCS.
- There is accurate fixing of various threshold values by the HWSP including v_t, $Throughput_{Min}$, $Cost/Mb_{Max}$ and $Time\text{-}out_{Min}$ along with the periodic refresh rate to best suit the particular HWSP in question.
- There are provisions to maintain identical policies at both the EDA and the RDA and manipulate them with the change in user demands.

4.3.2 Policy Enforcer

The policy enforcer works by enforcing the user preferences expressed in terms of policies. It is supposed to block unwanted and suboptimal access networks from taking part in the decision process. It acts as the first phase of the elimination in the selection process. There are policy enforcers at both the ME and SCS, so that both the EDA and RDA can have access to them. Consistency among these two policy enforcers is to be maintained.

As in the case of any policy framework the policy enforcer also has a Policy Repository, Policy Decision and Policy Enforcement Point (PEP), all of which work together to achieve the desired task. The policy repository can be modified and appended by the user through the service provider. Figure 12, shows parts of the policy enforcer.



Network ID	Rx Level	Cost/Byte	Cost –Utility Fn
N_2			
N_3			
N_4			
N_5			

Figure 12: Policy Enforcer

Some common policies that can be enforced by the PEP include Minimum Entry Policy (MEP), Power Policy and Security Policy. The MEP being the most important makes sure that no networks that are blocked or suboptimal are considered in the later stage of the decision process. The threshold values to qualify the MEP are set by the HWSP. More intricate policies can be also tailored to reflect special case scenarios and specialized user needs such as the Preferred Network Policy and Load Balancing policy.

4.3.3 Location Velocity Module (LVM) and Seamless Connection Server (SCS)

The Location Velocity Module (LVM) being part of the ME plays an integral part in the working of the proposed framework. It is the reporting of the current location and velocity of the LVM to the SCC that decides where the decision process should take place. Any adequately accurate technology covered in the section 2.5, can be used to obtain these values.

The SCC in the ME maintains a periodic refresh function that tracks all the potential networks and updates decision tables at the EDA or the RDA at constant intervals. The refresh interval of the periodic refresh function is fixed by the service provider in such a way to best serve the users. The SCC also passes triggers from event handlers to the algorithms regarding change in application selected, current user velocity or any user or network event that requires immediate attention.

4.3.4 Location Information Server (LIS) and Time-out Calculations

In our proposed framework the location Information Server (LIS) is implemented in the SCS of the HWSP. Any fairly accurate technological implementation of the LIS, detailed in section 2.3, can be employed for the framework. A Time-out Calculation Module is also included in our LIS along a RAN map and QOS parameter Indicator. In this section, we examine the interaction of the LIS with the other parts of the SCS.

The main reason to use LIS in the SCS is to support fast moving users with their handoff needs. The RDA, in order to complete its decision process, makes two requests to the LIS. The first one is to find out the available RANs and their corresponding QoS parameters at the user's current location. The other request made by the RDA involves calculation of the timeout values of those networks that passed the first phase of the selection process. The LIS uses its Time-out Calculation Module to provide time-out values back to the RDA. The RDA uses this information to populate its decision tables. These two requests can also be merged into one request for faster response. When the RDA receives the periodic refresh function from the SCC, it uses that to refresh its request to the LIS and thus in turn refresh the RDA decision table. This helps it in maintaining an up-to-date RDA decision table.

Chapter 5

Validation and Analysis

This chapter presents a demonstration of the proposed solution's functionality, limitations and benefits. Section 5.1 depicts the solution's capabilities and limitations by applying it to a particular scenario and thus evaluating it qualitatively. Section 5.2 presents a quantitative evaluation of the solution's performance, by simulating it in ns-2. The chapter ends with section 5.3, which gives a brief list of benefits and limitations of the proposed architecture and also investigates potential environments and business processes that would benefit from this model.

5.1 Qualitative Evaluation and Demonstration

The following scenario was designed to demonstrate the performance of the system and qualitatively evaluate the way the system deals with user mobility. The scenario simulates a typical day in the life of a researcher working for a tech company. The user commutes to the office from home on his company bus. The bus takes two separate routes to get to the office and then back home at the end of the day. The researcher prefers not to waste his time on transit and thus makes use of various services provided by his ME and HWSP. In the paragraphs to follow, a description of each stage of the scenario and explanations of the calculations leading to the final network selection decision at those steps are given.

(a) In the house

After getting up the user uses his ME to check his stock quotes and read the morning news.

Vc <Vt → EDA	
Potential Networks	$Home\_WLAN, UMTS, WiMAX_1$
Application(s)	Web Browser

Table 1: Potential networks in the house

As the current velocity is found to be less than the velocity threshold, the decision will take place in the EDA module of the ME. The Home_User_Policy stipulates that the ME has to explicitly use the $Home\_WLAN$ network for any services, if it is in range and has an acceptable Throughput. Because of the existence of this policy only PHASE 1 of the decision process is required to come up with a suitable network for the user.

PHASE 1→ The EDA Policy enforcer while populating the EDA Decision Table detects the $Home\_WLAN$. It confirms that its Throughput is higher than the stipulated value and then selects $Home\_WLAN$ as the candidate network.

(b) Inside the Bus to Office

The user waits for the bus in front of his house and takes it to get to his office. The bus takes route X to reach the office. In the bus the user sends emails to his peers confirming the day's meeting and also uses the browser to download the report of the meeting he has to attend.

Vc >Vt → RDA	
Potential Networks	$UMTS, WLAN_1, WLAN_2, WiMAX_1, WiMAX_2$
Application(s)	Web Browser

Table 2: Potential networks inside the bus to office

As the bus begins to move the velocity picks up. When the velocity is above the threshold velocity, the RDA at the SCS is picked for making the decision by the SCC. Mobile reporting of the surveyed QoS parameters, current velocity and location coordinates are also passed to the SCS.

PHASE 1→ The RDA Policy Enforcer populates the RDA Decision Table with potential networks' Throughput, Cost/Mb and Time-out value obtained by querying the LIS and the Time-out Calculation Module. The Minimum Threshold Policy (MTP) in the Policy Enforcer's Policy Repository makes sure that only those networks that satisfy the minimum entry Throughput, Cost/Mb and Time-out values set by the HWSP are given entry into the RDA Decision Table. The threshold values for our MTP are set as 0.1, 8 and 0.5 for Throughput ($Throughput_t$), Cost/Mb ($Cost / Mb_t$), and Time-out ($Time{-}out_t$) values respectively. The selected networks make their way into the second phase of the selection process.

NID	Throughput	Cost/Mb	Time-out value
N1 $UMTS$	.25	8	2
N2 $WiMAX_1$	7	6	1.8
N3 $WiMAX_2$	6	5	1.6
N4 $WLAN_1$	3.4	4	.6
N5 $WLAN_2$	1.1	5	.6

Table 3: Phase 1 RDA Decision Table for scenario b

PHASE 2→ The RDA decision table obtained from the first phase is again filtered, but this time using the selected application's Application Threshold. The selected application is Web Browser and its Application Threshold is given in the table. When this threshold is applied all the networks other than N3 and N5 are eliminated. After applying the Application Threshold, the best of the networks N3 and N5 is selected by applying the cost utility function.

Application Threshold
Web Browsing
$Throughput_{Min} = 0.2$ $Cost / Mb_{Max} = 5$ $Time\text{-}out_{Min} = 0.6$

Table 4: Application Threshold for Web Browsing

NID	Throughput	Cost/Mb	Time-out value	Cost-Utility
N1 $UMTS$	.25	8	2	
N2 $WiMAX_1$	7	6	1.8	
N3 $WiMAX_2$	6	5	1.6	**1.2**
N4 $WLAN_1$	3.4	4	.6	
N5 $WLAN_2$	1.1	5	.6	0.22

Table 5: Phase 2 RDA Decision Table with Cost-Utility for scenario b

The Cost-Utility function tries to find the maximum positive difference between the Throughput and Cost/Mb of the selected networks. Here the Cost-Utility ratio for N3 is obtained by dividing 6 by 5, which gives 1.2. The same way the Cost-Utility function of N5 is obtained as 0.22. Picking the higher Cost-Utility function of N3 and N5 we get N3. Thus the network N3 ($WiMAX_2$) is found to be the best suited network for using the ME web browser in this case.

(c) At the office

The user arrives at the office and starts working. At work he makes some calls, sends some emails and also attends a video conference.

Vc <Vt → EDA	
Potential Networks	$UMTS, WiMAX_1, WLAN_3, WLAN_4, Corporate\_WLAN$
Application(s)	Web Browser, VOIP Call, Streaming Video

Table 6: Potential Networks at the office

In this case also the user can explicitly declare a policy to use the $Corporate\_WLAN$ whenever it is in range and in good strength. The reason for this is that the corporate network could have better bandwidth, security and cost benefits for the user.

(d) Walking towards the Coffee Shop

After work the user goes to the coffee shop outside his company to meet his friends. In the coffee shop, he sends SMS messages to his friends to let them know that he is waiting for them. As his friends are running late, he decides to pay off some of his bills.

Vc <Vt → EDA	
Potential Networks	$UMTS, WiMAX_1, WiMAX_2, WLAN_4, WLAN_5, CoffeShop\_WLAN$
Application(s)	SMS, Secure Browsing

Table 7: Potential Networks on the way to the coffee shop

PHASE 1→ The minimum entry policy and other relevant policies are applied and the filtered list of networks picked by the EDA policy enforcer is used to populate the EDA decision table. The EDA decision table is represented in table 8.

PHASE 2→ The user first selects SMS and then goes on to pay his bills using secure browsing. The Application Threshold of the SMS application is given in the table. After applying the Application Threshold for SMS only UMTS1 is eliminated. So, the cost utility function is applied to all the other networks in the list to select the best among them.

Even though all these networks may look more than capable to carry the SMS messages, the fact that the $CoffeShop\_WLAN$ is free of charge make it the best suited network. See the cost utility calculation table. As before the network with the highest value for the cost utility function is selected and in this case it is N6 ($CoffeShop\_WLAN$).

NID	Throughput	Cost/Mb
N1 $UMTS$	.25	8
N2 $WiMAX_1$	5	6
N3 $WiMAX_2$	6	5
N4 $WLAN_4$	3	4
N5 $WLAN_5$	4.5	4
N6 $CoffeShop\_WLAN$	2	0

Table 8: Phase 1 EDA Decision Table for scenario d

Application Threshold
SMS
$Throughput_{Min} = 0.1$ $Cost/Mb_{Max} = 6$

Table 9: Application Threshold for SMS

NID	Throughput	Cost/Mb	Cost-Utility Fn
N1 $UMTS$	.25	8	
N2 $WiMAX_1$	5	6	0.83
N3 $WiMAX_2$	6	5	1.2
N4 $WLAN_4$	3	4	0.75
N5 $WLAN_5$	4.5	4	1.25
N6 $CoffeShop\_WLAN$	2	0	2*

Table 10: Phase 2 EDA Decision Table with Cost-Utility for scenario d

After sending the SMS, the user proceeds to pay his bill. When the user opens the secure website the EDA policy enforcer understands that the user needs secure browsing and invokes the Secure_Browsing_Policy. As per the users Secure_Browsing_Policy secure transactions are only allowed on the Home_WLAN, UMTS or the $Corporate\_WLAN$, where the user is sure about the security of the network. So, even though the free $CoffeShop\_WLAN$ is available and there are other cheaper alternatives the decision to use UMTS is made.

(e) Inside the Bus to Home

After meeting his friends the user takes his company bus back to his house. The bus takes Route Y to get back to his house. In the bus the user decides to watch the live hockey match by streaming the video to his ME. The bus reaches home and the user gets down.

Vc >Vt → RDA	
Potential Networks	$UMTS, WiMAX_1, WiMAX_2, WLAN_6, WLAN_7, WLAN_8$
Application(s)	Web TV

Table 11: Potential Networks on the bus to home

PHASE 1→ After the Minimum Entry Policy (MEP) and other relevant policies are applied and the filtered list of networks picked by the RDA policy enforcer is used to populate the RDA decision table. As in case b, the LIS and Time-out Calculation Module in the SCS help in filling the fields of the table. The RDA decision table is represented in table 12.

PHASE 2→ The selected application is streaming live video. The Application Threshold is shown in the table and after applying it only two networks remain of the original six. They are N2 and N3. The cost utility function is applied on the N2 and N3 and the network with higher Cost-Utility function N2 ($WiMAX_1$) is selected.

NID	Throughput	Cost/Mb	Tim-out value
N1 $UMTS$	.2	7	10
N2 $WiMAX_1$	7	5	5
N3 $WiMAX_2$	3	4	3
N4 $WLAN_6$	3	4	.7
N5 $WLAN_{7}$,	2	4	.6
N6 $WLAN_8$	.1	3	.5

Table 12: Phase 1 RDA Decision Table for scenario e

Application Threshold
Streaming Live Video (Web TV)
$Throughput_{Min} = 0.2$ $Cost / Mb_{Max} = 5$ $Time\text{-}out_{Min} = 1$

Table 13: Application Threshold for Web TV application

NID	Throughput	Cost/Mb	Tim-out	Cost-Utility
N1 $UMTS$	.2	7	10	
N2 $WiMAX_1$	7	5	5	**1.4**
N3 $WiMAX_2$	3	4	3	0.75
N4 $WLAN_6$	3	4	.7	
N5 $WLAN_{7}$,	2	4	.6	
N6 $WLAN_8$	.1	3	.5	

Table 14: Phase 2 RDA Decision Table with Cost-Utility for scenario e

The user having reached home and gets down from the bus. As soon as the ME detect the *Home_WLAN*, effort is made to transfer the current application's connection point to the *Home_WLAN*. This is achieved by a soft handover and the user continues to watch rest of the game in his home network

5.2 Quantitative Performance Evaluation

This section describes the quantitative validation of the proposed decision mechanism. First, it explores various validation techniques used in the literature and provides the basis for using the particular validation technique selected to validate this thesis effort. The second part examines in detail the various parameters, assumptions and scenarios used in the validation of the proposed system.

In [LBH$^+$08] the authors explore methodologies to assess vertical handover selection algorithms in heterogeneous wireless networks. They observe that test case scenarios to assess decision algorithms are quite difficult to design and implement. The authors go on to argue that this is because the test-case emulations are difficult to put in practice and performance usually depends on other auxiliary mechanisms such as user profiling and other decision parameter gathering mechanisms. It was inferred that a comprehensive methodology or any common metric for evaluating or comparing the various network selection techniques does not exist in the literature. However, a methodology for evaluating vertical handoff selection mechanisms that uses multiple attributes decision methods was proposed by [SGB06]. Even though [SGB06] is thought to be a good model to compare MADM based techniques, most proposed MADM methods depend on use case scenarios to validate their proposed decision process [SJ05]. [BL07] uses four different use case scenarios to validate its proposed decision process. [ADK$^+$05] applies its decision process in a framework of scenarios to simulate a typical day in the user's life. Effort was also made in some research work to demonstrate the dynamic decision capability of their work (such as reaction to a temporary reduction in cost) [YJK$^+$03].

Comparisons to weight based MADM models were found to be difficult as it was observed that the assigned weight varies in different situations. Comparing and evaluating by quantification of different attributes using fuzzy terms does not work outside the realm of MADM models. This is more so in the case of our proposed system, where instead of using multiple attributes (security level, average delay, bit rate error, user preferences, operator constraints, resource utilization, terminal context and other intricate application requirements), just two vital attributes namely, Throughput and

Cost/Mb are used to pick the best network at any moment. The other minor attributes and details are left for the policy engine and the Application Threshold delimiter to deal with and thus the decision process becomes simpler and more straight forward.

The majority of the evaluations of proposed selection mechanisms were found to be rather simplistic and often limited to the evaluation of only a subset of the whole mechanism architecture, namely the selection decision algorithm [PP03] [MPK04] [WLM05] [BL06] [SGB06]. A few other works use a set of different evaluation metrics to evaluate the performance of their respective mechanisms. The main metrics used are average power consumption cost, average preference dissatisfaction, rejection rate, number of handoffs performed by the mobile terminal, networks utilization, the available bandwidth and packet delay [CKA06] [ADK$^+$05] [BL07] [YJK$^+$03]. [SGB06] claims that the metrics used by these works do not allow rigorous and concrete comparison of the performances of novel proposed mechanisms, and there is need for a novel standard set of matrices.

In order to validate the proposed system, it was applied in a variety of test cases. The adoption of the test case based validation was done after reviewing the validation techniques used to evaluate other decision mechanisms in the literature. It was also observed that test cases provide a systematic way of collect, analyze and report data and at the same time obtain information as to what to look for more extensively in future research [BEN06]. In this validation effort, test cases were created to capture the capabilities of the proposed design. The findings were then compared to a signal strength based decision mechanism [WEL84] and a Cost-Utility model [OPM05], which is partly similar to the proposed model. The network selected when a particular application is used is recorded and then plotted in a graph. The cost of the decision is calculated based on fixed price scheme and provided for each of the following cases: decision in regular conditions, after the Cost/Mb associated with the network changes and under new Throughput conditions. An effort was also made to quantify the user's willingness-to-pay [SAA$^+$04] and the observed consumer surplus [JA02], in cases where they exist.

There are some assumptions made for the design of the simulations scenario, they are as follows. It is assumed that all the networks considered in the scenarios have passed the policy enforcer and thus meet the Minimum Entry Policy (MEP) as defined in section 4.3.2. It is also assumed that when the mobile switches over from one network to another the handover delay is very negligible. In other words, the handover delay and other delays involved in the switching over were not considered. In the mobile side decisions using EDA, it is assumed that there is the existence of a mechanism to update the ME about various QoS parameters. Any of various techniques such as beacons, dedicated signaling, SLAs or out of band signaling can be employed to achieve this. It is assumed that each user has filled a user questionnaire to depict the maximum cost he is willing to pay for various services and applications that he intends to prior to setting up of the connection. The pricing scheme used in the simulation to calculate the cost incurred by an application is the fixed pricing scheme. All the considered networks in the scenarios are assumed to have the capability to service any of the considered application at any time. Here the main aim was to find the network that would be the best fit to the user's specific requirements at that particular time.

The validation was done using Network Simulator 2, with 802.11infrastructure extension. To design the proposed scenario four WLAN access points (APs) were chosen and placed in a grid of size 560x560 in such a way that the grid has full wireless coverage (with no gaps). The access points, namely W1, W2, W3 and W4 are used to represent four different internet access providers with various QoS parameters. The ME senses a throughput of 2 Mbps, 5.5 Mbps, 5.4 Mbps and 1 Mbps for the networks W1, W2, W3 and W4 respectively. The Cost for accessing these networks are given as 4, 7, 6 and 0, for each megabit used. A MN is placed in the grid that can select any one of the APs at any time to satisfy its wireless needs. Another wired node is placed outside the grid area to act as a sink for the wireless traffic. To emulate the MN connecting to the available APs and using various applications, three different connections of varying duration are established between the MN and the wired node. Here the MN acts as the source of the traffic and the wired node acts as the sink. The design topology is shown in figure 13.

The order of connections established between the MN and the wired nodes is as follows. First a TCP connection is established to send 15 Mb of data to represent a large file download. After that the connection is reset and another TCP connection is established to send 1 Mb data to represent an MMS message. Lastly, in order to represent streaming video, a UDP connection is established to transfer 90 Mb of data.

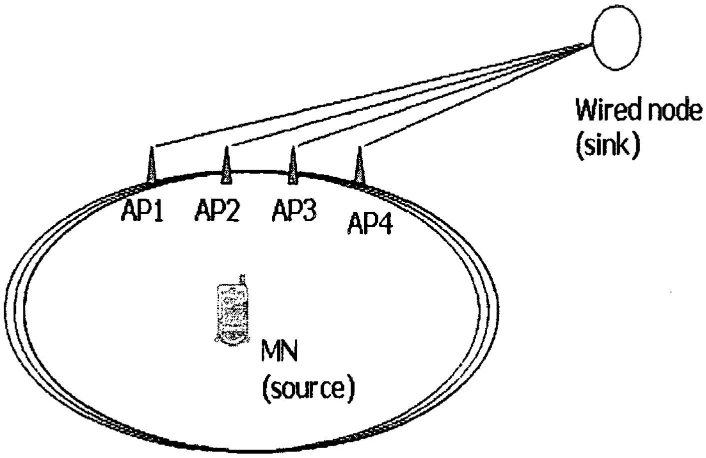


Figure 133: Design Topology

Here, it should be noted that only one connection is established for the life time of an application. In other words, the connection to the selected AP is not reset until the current application is terminated. There is no need to find a new AP half way through the application's life time because all the considered APs can cater to the needs of the designed applications at anytime, without major interruptions. Table 15 gives the characteristics of each application along with the Application Threshold as obtained from the user questionnaire, filled beforehand by the user. Table 16 shows the simulation time for each designed application.

Application	Size (MB)	Traffic Class	Application Threshold (from Questionnaire)
FTP	15 MB	Non Streaming class	Min 2 Mbps Data rate Max 6 Cents Cost/Mb **Min 15 Seconds**
MMS	1 MB	Non Streaming class	Min 1 Mbps Data rate Max 4 Cent Cost/Mb **Min 2 Seconds**
Video Streaming	90 MB	Streaming class	Min 2 Mbps Data rate Max 6 Cents Cost/Mb **Min 90 Seconds**

Table 155: Designed Applications

Action	Application	Time frame (Seconds)	Time (Seconds)
Warm Up	-	60	60
Send a large file	Download File	15	75
Send a very small file	MMS	1	76
Send very large file	Video Streaming	90	166
Shut down	-	44	200

Table 16: Application simulation suite

AP	Data Rate(Mb/Sec)	Cost/Mb	Cost-Utility
W1	2	4	0.5
W2	5.5	7	0.78
W3	5.4	6	0.91
W4	1	Nil	-

Table 17: EDA Decision Table under regular conditions in the Slow Moving User Scenario

In order to represent the fast and the slow moving users in the simulation, two sets of scenarios are designed. They are Fast Moving User Scenario and Stationary or Slow Moving User Scenario. The network decisions made by the proposed system in both these scenarios (to utilize the simulated applications) are compared with those made by the Signal Strength and the Cost Utility model.

Figure 14 represents the comparison of the proposed model in the Slow Moving User Scenario with other models. Figure 17 gives the cost incurred for each application by using the different decisions methods in the Slow Moving User Scenario. To demonstrate the dynamic decision capabilities of the proposed system in the Slow Moving User Scenario, the new decisions made after the cost per megabit (Cost/Mb) changes are depicted in figure 15. The cost per megabit changes to 2, 5, 6, and NIL for W1, W2, W3 and W4 respectively. Figure 16 represents the decisions after the

Throughput changes from 2, 5.5, 5.4 and 1 to 2, 5.4, 5.5 and 1. The figures 18 and 19 show the cost incurred for each application after the cost per megabit and Throughput is changed in the Slow Moving User Scenario.

Tables 18 and 19 depict the decision tables at the time of decisions in the cases where the Cost/Mb and Throughput changes. In all the three decision tables it can be observed that the Signal Strength model selects the network with the highest Throughput value and the Cost Utility model selects the network with the highest Cost-Utility ratio. The proposed method takes the Cost-Utility ratio of those networks that are filtered by the policy engine and approved by the Application Threshold obtained from the user questionnaire. For example, in table 18 when the cost is reduced for network W2 from 7 cents to 5 cents, it qualifies the Application Threshold for FTP applications set at a maximum cost of 5 cents per megabit and minimum Throughput of 2 Mbps and thus becomes the candidate network with highest Cost-Utility ratio. The same decision for this application, under regular condition is different because the prescribed Application Threshold is not met in that case.

AP	Data Rate(Mb/Sec)	Cost/Mb	Cost-Utility
W1	2	2	1
W2	5.5	5	1.1
W3	5.4	6	0.9
W3	1	Nil	-

Table18: Decision Table after the Cost/Mb changes in the Slow Moving User Scenario

AP	Data Rate(Mb/Sec)	Cost/Mb	Cost-Utility
W1	2	4	0.5
W2	5.4	7	0.77
W3	5.5	6	0.91
W4	1	Nil	-

Table19: Decision Table after the Throughput change in the Slow Moving User Scenario

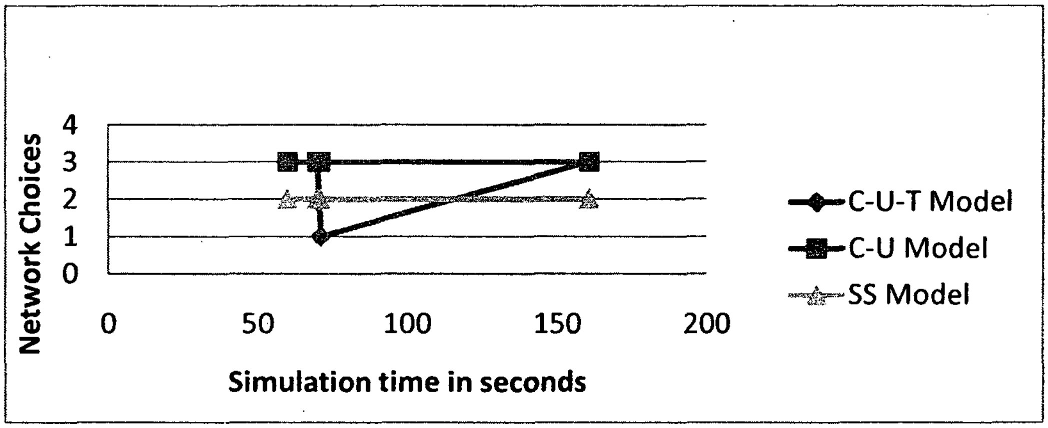


Figure 14: Network Decisions at Regular Conditions in Slow Moving User Scenario

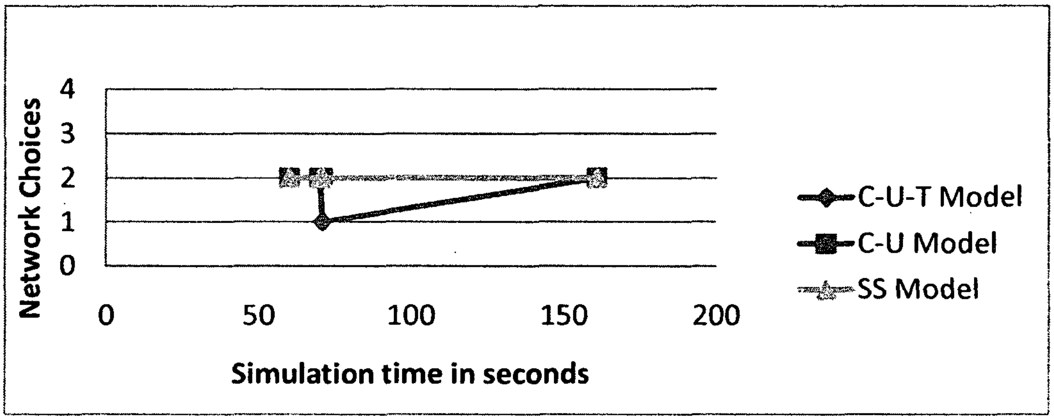


Figure 15: Network Decisions after Cost/Mb Change in Slow Moving User Scenario

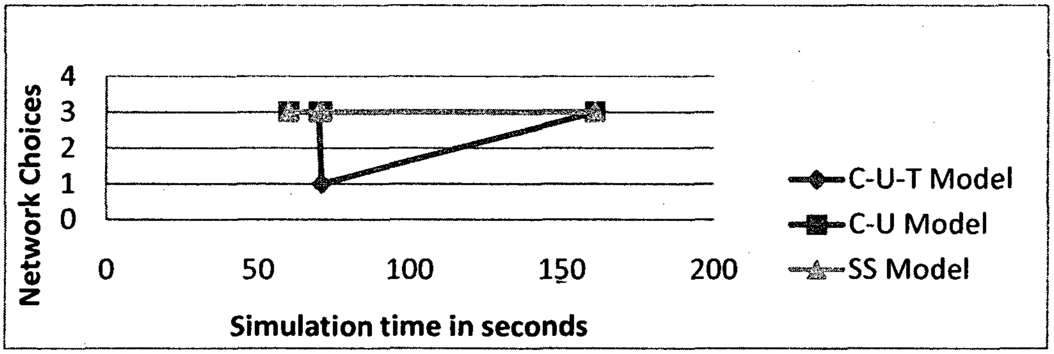


Figure 16: Network Decisions after Throughput Change in Slow Moving User Scenario

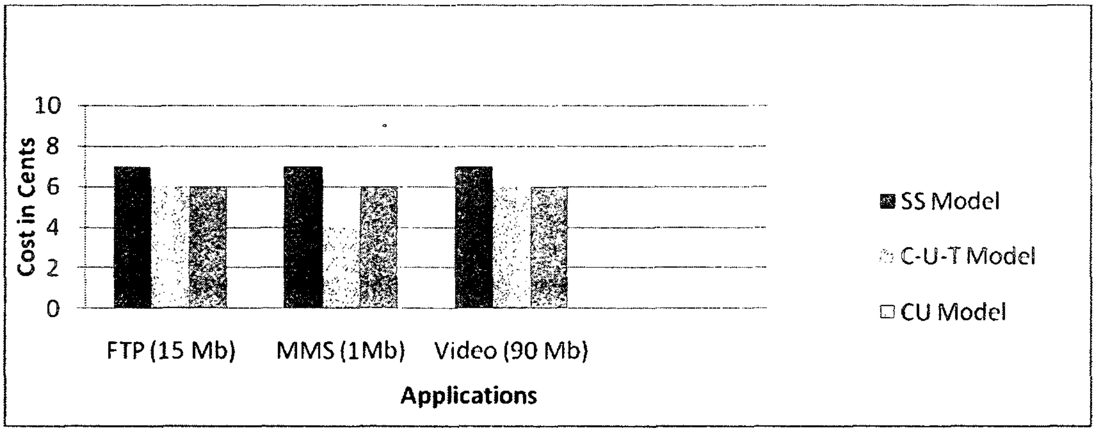


Figure 17: Cost Incurred under Regular Conditions in Slow Moving User Scenario

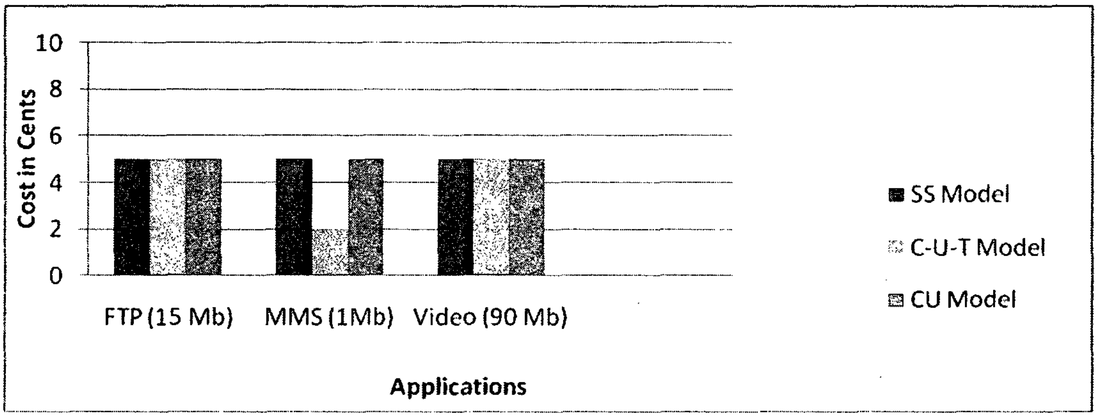


Figure 18: Cost Incurred after Cost/Mb Change in the Slow Moving User Scenario

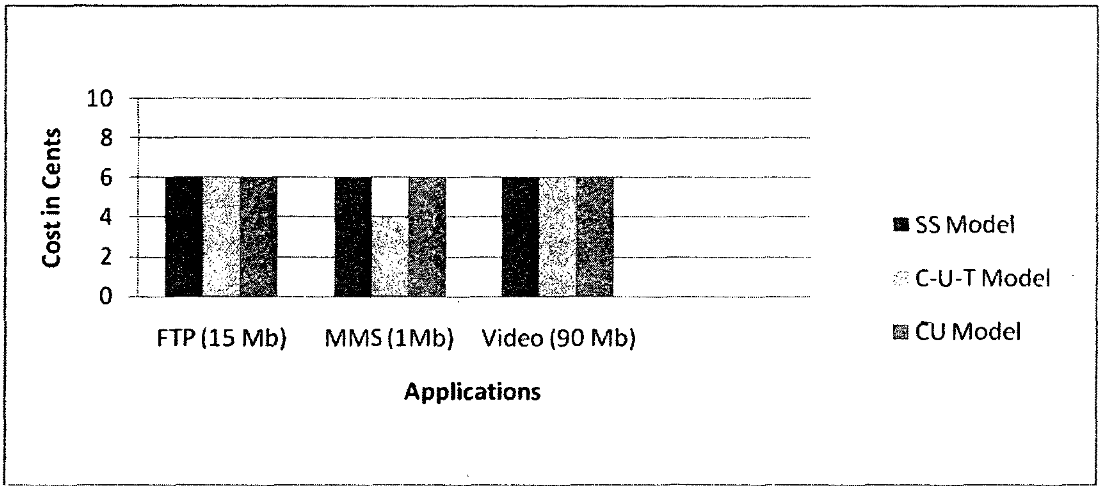


Figure 19: Cost Incurred after Throughput Change in the Slow Moving User Scenario

Till now, we have considered the scenario were the user is stationary or moving at very slow velocity. In other words the user's current velocity (Vc) is less than the Threshold Velocity (Vt) set by the HWSP. Now, we will consider the cases where the user's velocity is above the stipulated threshold.

In the Fast Moving User Scenario, the following assumptions are made for the simulation. It is assumed that the ME can move inside the simulation grid from one end to another with a constant speed of 10 meter/second, this is the Vc. The Velocity Threshold set by the HWSP is 7 meter/second. The actual Throughput experienced by the ME is assumed to be half the actual data rate of the servicing AP, except for AP W4, which has 1 Mb Throughput. So, the estimated time to complete the applications FTP, MMS and Video Streaming are 15, 1, and 90 seconds respectively. Since, Vt here is more than Vc the decision takes place at the RDA on the server side and with inputs from the LIS. The Time Out values provided by the LIS for the APs W1, W2, W3 and W4 are assumed to be 100+ (more than hundred), 15, 15 and 1 seconds.

AP	**Data Rate (Mb/Sec)**	**Actual Throughput (Mb/Sec)**	**Cost/Mb (Cents)**	**Time Out (Seconds)**	**Cost-Utility**
W1	2	1	4	100+	0.5
W2	5.5	2.75	7	15	0.78
W3	5.4	2.7	6	15	0.91
W4	1	~1	Nil	1	-

Table 20: RDA Decision Table under regular conditions in the Fast Moving User Scenario

Similar to the Slow Moving User Scenario, the Fast Moving User Scenario's decision tables and decisions calculated under regular situations and those under changing Cost/Mb and Data rate conditions are represented in tables 20, 21 and 22 and in figures 20, 21 and 22 respectively. The costs incurred under these circumstances are represented in the figures 24, 25 and 26. In last decision table, table 23, the Time Out value is changed to more than one hundred seconds for all the APs. It can be observed that in this circumstance the decision figure and the cost incurred are same as that of the Slow Moving User Scenario (see figures 23 and 27).

AP	Data Rate (Mb/Sec)	Cost/Mb (Cents)	Time out (Second)	Cost-Utility
W1	2	2	100+	1
W2	5.5	5	15	1.1
W3	5.4	6	15	0.9
W4	1	Nil	1	-

Table 21: Decision Table after the Cost/Mb Changes in the Fast Moving User Scenario

AP	Data Rate (Mb/Sec)	Cost/Mb	Timeout (Seconds)	Cost-Utility
W1	2	4	100+	0.5
W2	5.4	7	15	0.77
W3	5.5	6	15	0.91
W4	1	Nil	1	-

Table 22: Decision Table after the Throughput Changes in the Fast Moving User Scenario

AP	Data Rate (Mb/Sec)	Cost/Mb (Cents)	New Time Out (Seconds)	Cost-Utility
W1	2	4	100+	0.5
W2	5.5	7	100+	0.78
W3	5.4	6	100+	0.91
W4	1	Nil	100+	-

Table 23: Decision Table after the Time Out Value Changes in the Fast Moving User Scenario

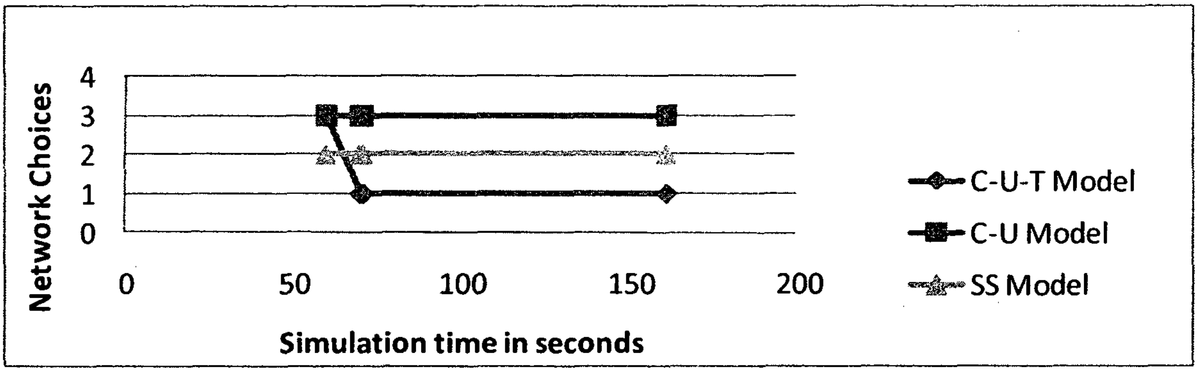


Figure 20: Network Decisions at Regular Conditions in Fast Moving User Scenario

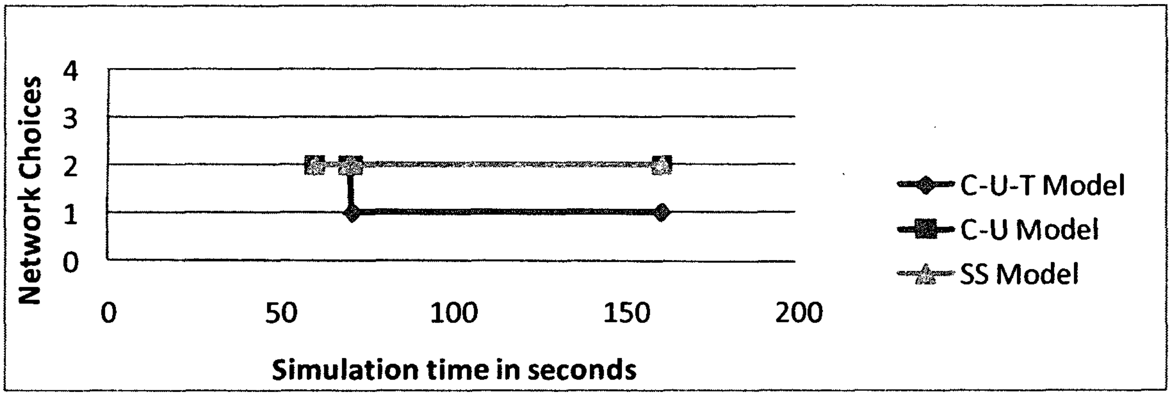


Figure21: Network Decisions after Cost/Mb Change in Fast Moving User Scenario

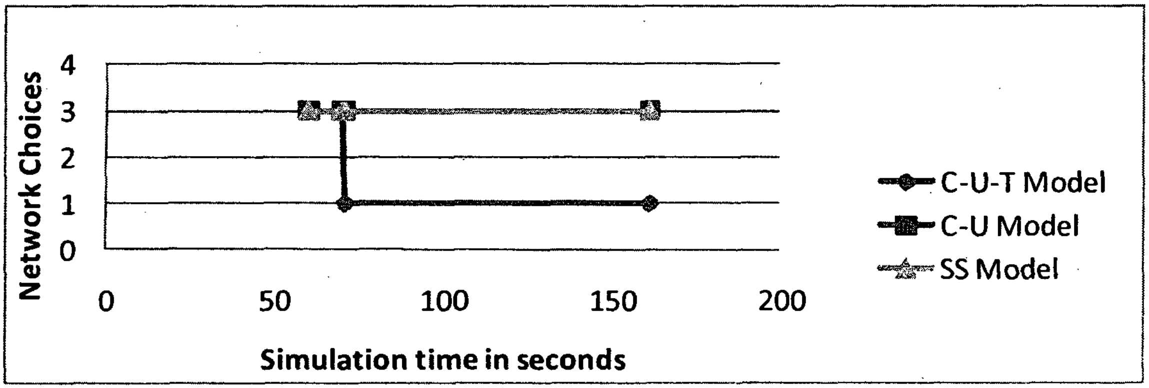


Figure 22: Network Decisions after Throughput Change in Fast Moving User Scenario

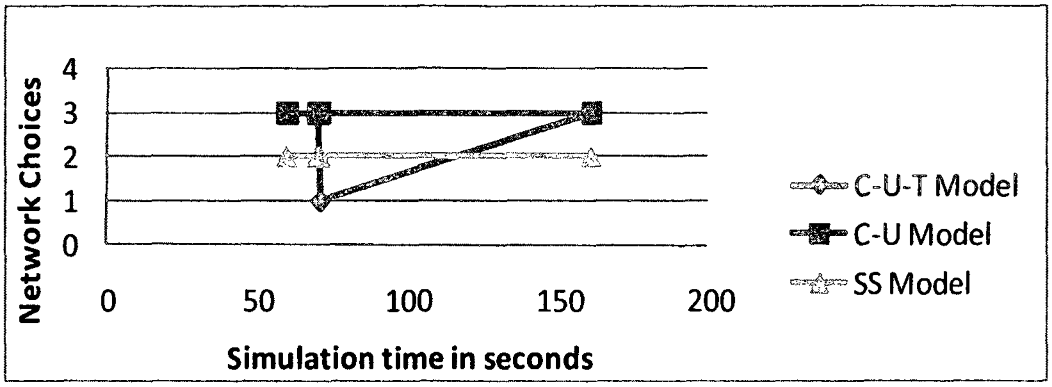


Figure 23: Network Decision after Time Out Change in Fast Moving User Scenario

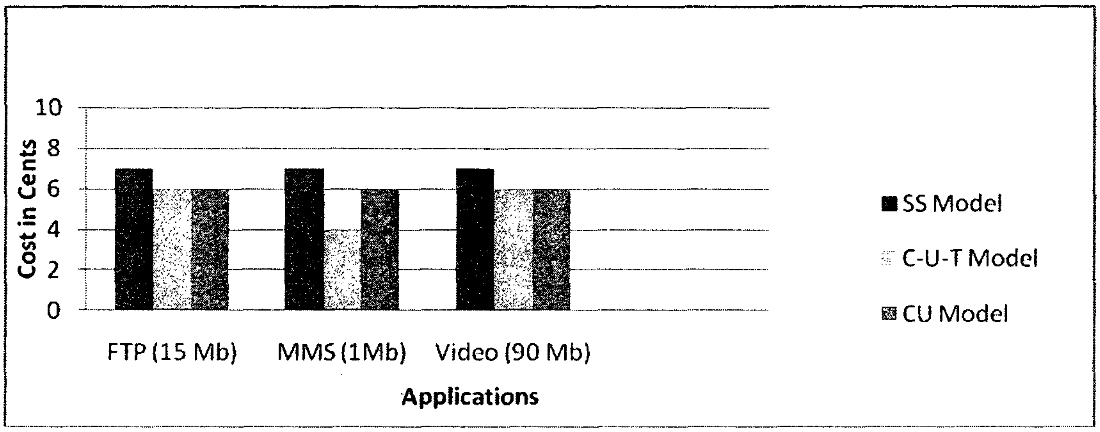


Figure 24: Cost Incurred under Regular Conditions in Fast Moving User Scenario

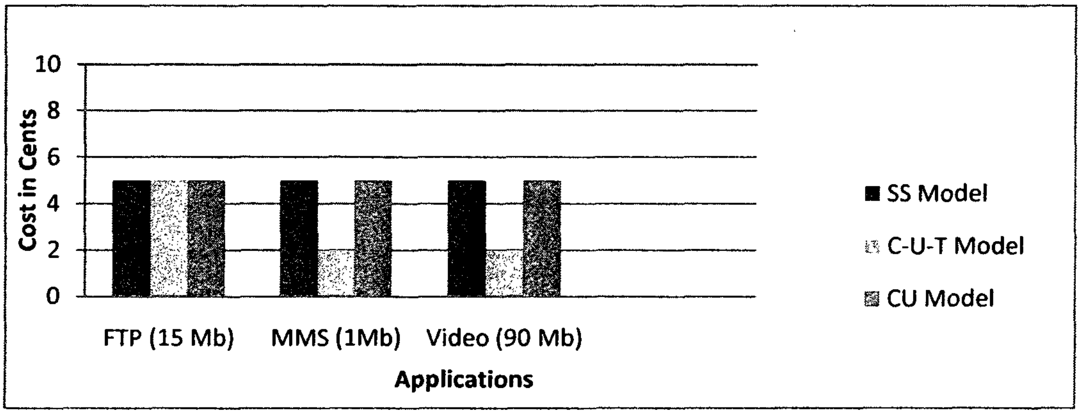


Figure 25: Cost Incurred after Cost/Mb Change in Fast Moving User Scenario

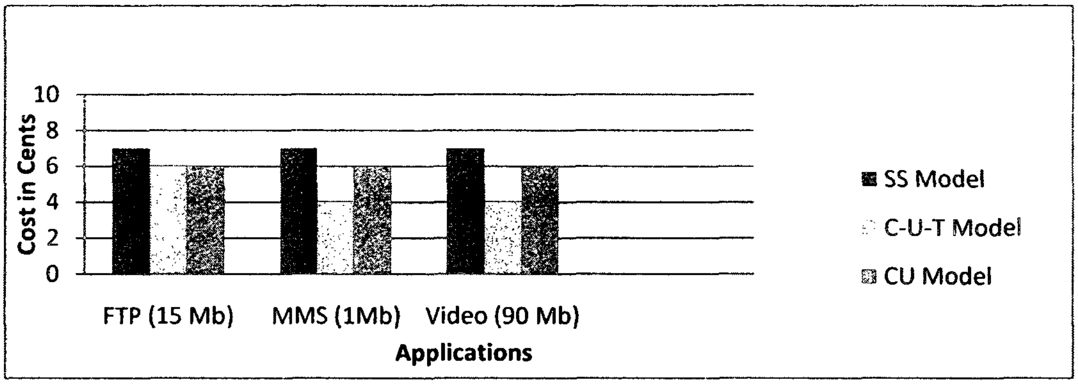


Figure 26: Cost Incurred after Throughput Change in the Fast Moving User Scenario

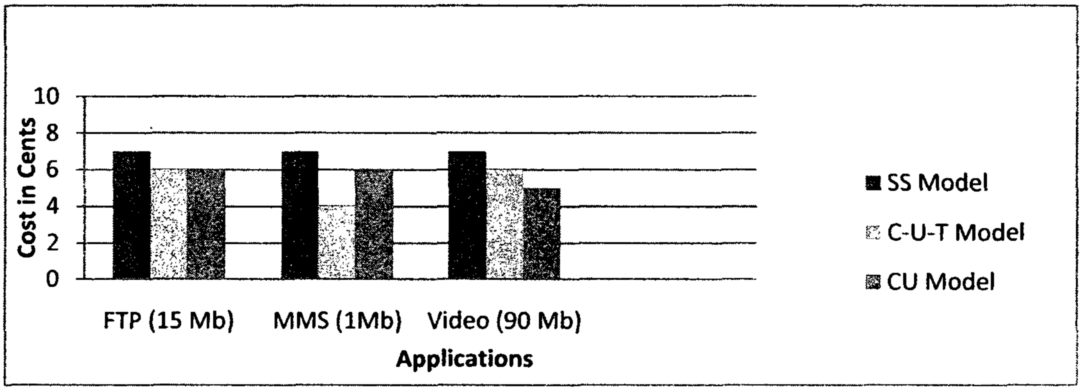


Figure 27: Cost Incurred after Time Out Change in the Fast Moving User Scenario

From the above mentioned simulation scenarios it can be gathered that the proposed decision mechanism can help pick networks that corresponds to the user's Throughput and Cost requirements, which are specific to the applications he intend to use. Rather than offering a flat rate for the services obtained the user can look for the best price that suits his budget. The selection mechanism is also tested for its ability to adapt to changes in the QoS in a dynamic environment.

Table 24 represent the customer questionnaire filled by the customer before the subscription is set up. It is used to capture and quantify the user's willingness to pay. In the table the user has chosen the silver payment option and it is represented in figure 28. The proposed system decisions made under regular conditions along with decisions made by the Signal Strength model and the Cost Utility model are also represented in the graph.

This graph can be used to demonstrate the consumer surplus the proposed model exhibits in each given situation. It was observed that by increasing the consumer surplus we can theoretically increase the consumer satisfaction [HB96].

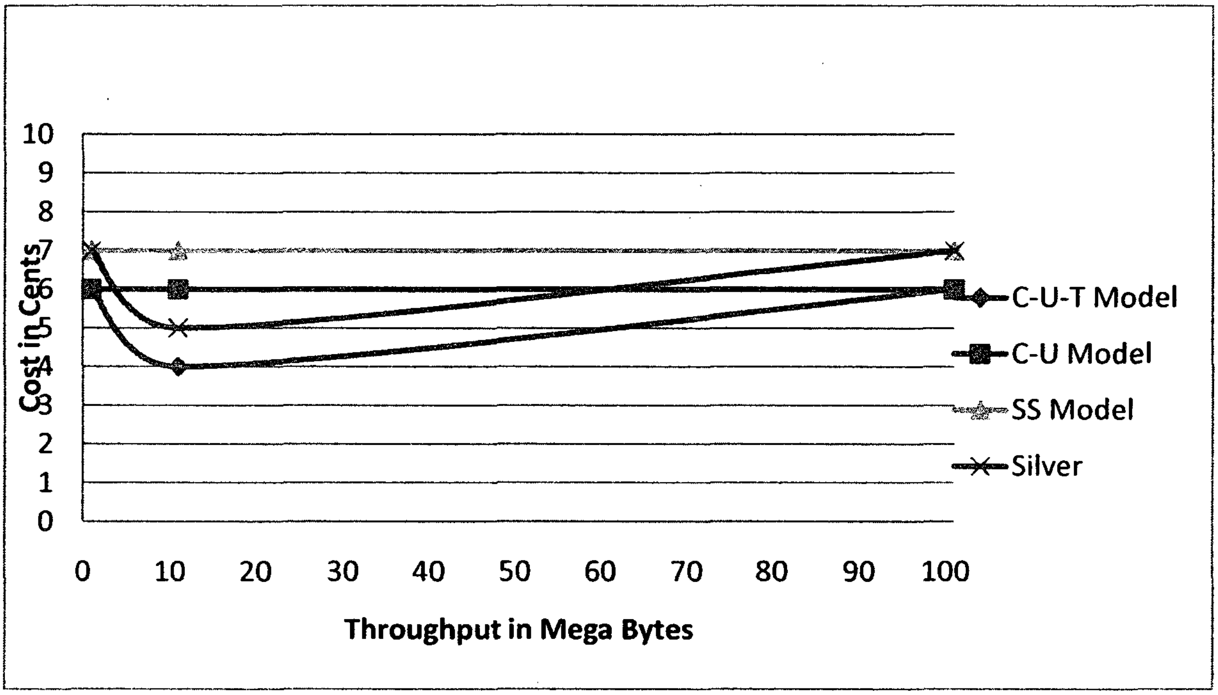


Figure 28: Consumer surplus under regular condition

APPLICATION	GOLD	SILVER	BRONZE
FTP	Min 5 Mbps Max 10 Cents	**Min 2 Mbps** **Max 7 Cents**	Min .5 Mbps Max 1 Cent
MMS	Min 2 Mbps Max 10 Cents	**Min 1 Mbps** **Max 5 Cents**	Min .25 Mbps Free
STREAMING VIDEO	Min 5 Mbps Max 10 Cents	**Min 2 Mbps** **Max 7 Cents**	-NA -

Table 24: User Questionnaire

5.3 Benefits, Limitations and Suitable Environments

5.3.1Benefits

Along with the benefits claimed by conventional network selection techniques our solution if well implemented can have the following benefits also.

* **Flexibility and Scalability:** Our solution for the network selection problem was designed with flexibility of its implementation in mind. It was observed that the ability of any solution to adapt and scale to the realities on the ground is crucial to its successful adoption. By providing flexibility in selecting and setting threshold values and Application Thresholds, HWSPs can tailor services to their clients needs. The HSWP can decide where the decision process is to take place by tweaking the velocity threshold. The default set of policies can also be extended by the HSWP by adding his own. An example of this could be the adding of load balancing policy, which enables overall network planning and optimization by the HWSP for the Network Service Providers. If the HWSP wishes to do so, he can even substitute the EDA and RDA, which work on the Cost-Utility principle, with other relevant algorithms that would better serve his needs.

* **Reduced delay:** With the help of a fully functional LIS, the HWSP can put the network adapters in the ME to the active solicit mode, by providing the name of the channel to search for in each geographical location. This helps save the time spent on periodic search across all channels and access networks. Thus, instead of waiting for the beacon from the AP to reach the ME, it can perform an active search and reduce the overall delay involved.

* **Easy Billing:** Another benefit of the framework is that it can provide the HWSP user with a consolidated bill for all the services he consumes. So, instead of user having to subscribe to each individual service provider, a 'pay-as-you-go' model can be used. In this scenario the user has the freedom to pick the network service providers who would best serve his current data needs. The network service providers can vie for more

customers by lowering their prices or increasing their QoS and coverage. Thus, the end user will benefit for better priced services.

* **Enhanced user experience:** One major design goal of this thesis was to enhance the end user experience. It was noted that if the user does not find that he has control over the decision process he would be reluctant to use this service. In order to ensure that the final decision lies with the user, the Application Threshold values are set based on a subscriber questionnaire collected from the user. The user can also define his specialized needs by special policies with the help of the HSWP. An example of this would the Blocking policy, which include the list of networks that the user never wishes to connect to. Other benefits for the user include a warning of areas with no connectivity and graceful degeneration of services instead of sudden disconnection. Both of these can be achieved with the help of the Time-out Calculation Module in the SCS, which can notify the ME. The users also stands to benefit from the 'pay-as-you-go' model mentioned earlier by picking a network to suit their particular requirement and leaving all the intricacies of connecting to the HWSP.

5.3.2 Limitations

The major limitations of the architectures are as follows:

* **Configuration:** It was observed that in the proposed architecture the configuration and calculation of various threshold values could be both vital and complicated. It is vital because the correctness and efficiency of the algorithm depends on the error free calculation of these values. So, the HSWP should make sure that correct methods are employed to find these threshold values, which are intrinsic to each network and user. Care should be also taken when calculating the Application Threshold values from the user questionnaire.

* **No Dedicated Signaling Channel:** The fact that the architecture cannot guarantee a direct signaling path to the SCS, where the LIS is maintained at all times can

be viewed as a limitation. Especially, when the current velocity is higher than the threshold velocity and would require the assistance of SCS. In these cases an inability to connect to the SCS would force the user to make the decision in the ME without the help of the LIS. The reason for this compromise is because there is no dedicated channel for signaling in our proposed solution as opposed to some surveyed solutions. Even though it could be argued that maintaining a dedicated signaling channel could be more power consuming, it can guarantee a connection to the SCS and thus have access to the LIS anytime.

* **Need for New Business Model:** Even though the Network Access Service Provider market is prime for change with the advent of multi-interface phones and growth of Wi-Fi, and WiMAX, there has to be a paradigm shift in business process models for the HSWP framework to work. There is a need for efficient SLA's between the access network providers and the HWSP. It would require major changes in existing business models and more compromises between the parties involved for this new architecture to take off.

5.3.3 Suitable Environments

The proposed solution is aimed at the service providers of heterogeneous connectivity. This solution has the potential to spur the creation of new business models and can increase the utilization of existing ones.

* Our architecture makes it easier for the user to make decisions and connect to the WiMAX network with ease and thus increase its demand. Utilizing WiMAX or Wi-Fi for making VoIP calls automatically will also make them popular.

*Other business models such as 'FON' also stand to benefit from our network selection technique. FON, whose members form the community Foneros, share some of their home Internet connection and get free access to the Community's FON Spots worldwide [FON]. As more FON group accounts become prevalent it is possible for the LIS to include it in the RAN coverage footprint and increase the connectivity options of the user.

The bottom line is that increased use of our automated network selection technique along with new billing models such as pay-as-you-go, can contribute to the exponential growth of new services. The user feeling liberated from the intricacies of making decisions to suit his needs can feel free to try new services that will suit his budget.

Chapter 6

Conclusion and Future Work

Although advances in cellular technology helps us to increase the voice and mobile data capabilities for the near future, these networks are thought to become capacity constrained in the long run. Thus, the use of new wireless network technologies to support high bandwidth mobile applications is inevitable. Future wireless systems are envisioned as being heterogeneous in that they will include a combination of various wireless access technologies such as 3G, WLAN, and WiMAX and would have a common IP core.

To seamlessly connect the wireless service providers in this heterogeneous environment, well devised network selection and handoff schemes are needed. This thesis effort surveyed the existing techniques that were proposed to overcome the network selection decision problem and at the same time tried to combine those techniques that were found to be effective. More effort was spent to achieve a good level of user satisfaction by making the entire selection process automatic based on the user's current application requirements, velocity, location and preference policies. Effort was also put to integrate the proposed decision model with existing technologies and provide a framework so that the entire concept can take form. The objective was to propose a new decision method with higher levels of scalability and flexibility that works in a novel business model termed Heterogeneous Wireless Service Provider (HWSP) with improved user experience as the goal.

The proposed solution was evaluated both quantitatively—by applying it to a number of different scenarios—and quantitatively—by simulating it in Network Simulator-2. In this evaluation, the proposed solution's capabilities, limitation and needed future modification were noted.

The proposed solution currently does not consider cases when more than one application is selected. Extending the solution to encompass handling multiple applications simultaneously will be useful. The viability of using the cellular network to ensure connectivity to the LIS is to be investigated, as this can enhance the performance of the proposed solution considerably. Extending the current validation model to include other RAN networks and highly mobile user can shed more light into the performance of the solution in those situations.

There is also a need for a comprehensive methodology for evaluating or comparing the various network selection techniques for the heterogeneous network environment. The existence of a standard set of metrics to rate novel network selection mechanisms based on their performance will also be very helpful for new proposals in this domain.

There can be immense potential in combining the proposed solution with the multi-homed mobile host proposal [YJK⁺03]. Even though this proposal to maintain connectivity to more than one RAN at the same time currently suffers from problems including excessive power consumption and interference, it is seen as a promising technique for ensuring seamless connectivity in future wireless networks.

Further study and research in areas such as–user specific policy creation, enhanced user requirement gathering methods, advanced pricing schemes and user location prediction schemes are needed. Advances in these topics are thought to be facilitated by the increasing processing power and capabilities of new mobile devices and advances in RAN technologies. It was observed that for seamless mobility to take off there is a need for new technologies, business models and even compromises from the part of the vendors and service providers to bring the different access network together.

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