Wireless Network Selection Algorithm for Multimedia Services in Heterogeneous Environment

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By

Kiran Ahuja

Reg. No. 950806010

UNDER THE GUIDANCE OF

Dr. RAJESH KHANNA
Supervisor
Professor, ECED
TU Patiala,
Punjab

Dr. BRAHMJIT SINGH
Supervisor
Professor, E&CE
NIT, Kurukshetra,
Haryana

Electronics Communication & Engineering Department

Thapar University,

Patiala-147004, Punjab, India.

CERTIFICATE

Certified that the thesis entitled, **"Wireless Network Selection Algorithm for Multimedia Services in Heterogeneous Environment"** being submitted by **Ms. Kiran Ahuja** University Roll No. **950806010** to Electronics and Communication Engineering Department, Thapar University, Patiala in fulfillment of the requirements for the award of the degree of 'Doctor of Philosophy' is the record of bonafide research work carried out by her under our guidance and supervision. The matter embodied in this thesis to the best of our knowledge and belief has not been submitted by the candidate in any other University / Institute for the award of any other degree or diploma.

(Dr. Rajesh Khanna)
Professor
Department of Electronics &
Communication Engineering
Thapar University
Patiala-147004 (Punjab)
India
Dated:

(Dr. Brahmjit Singh)
Professor
Department of Electronics &
Communication Engineering
National Institute of Technology
Kurukshetra-136119 (Haryana)
India
Dated: 15.08.2014

Signature of External Examiner (s)

Signature of Supervisor (s)

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A journey becomes easier when we travel together. Interdependence is certainly more valuable than independence. This thesis is a result of a consistent hard work and blessing of MATA RANI.

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ABSTRACT

The Next Generation Networks (NGNs) consist of different mobile and wireless technologies with varied operating characteristics. Due to complementary characteristics of different wireless networks, it is proposed to combine them to provide ubiquitous wireless access for users. The integration of Heterogeneous Wireless Networks (HWNs) requires the design of intelligent network selection algorithm to ensure seamless communication, and provide high QoS for different multimedia applications. The objective is to offer seamless multimedia services to users accessing all kinds of infrastructures through heterogeneous access technologies. The major focus of the present research work is on the network selection criteria for multimedia services in heterogeneous wireless network environment.

The research work aims to design and implement novel network selection algorithms in heterogeneous environments for multimedia services. The thesis is broadly divided into three parts to select network in various heterogeneous environment based on different criteria used. In first part, network selection based on QoS parameters in heterogeneous wireless networks is proposed by considering a heterogeneous environment consisting of UMTS, WLAN, GPRS, and WiMAX. It utilizes TOPSIS- a MADM algorithm based on AHP for network selection. Here, streaming is considered as a generic service. High weight has been assigned to delay whereas the packet loss and total bandwidth have been assigned lower weights and the least weight has been assigned to cost per byte to choose the appropriate connection out of four alternatives in context of seamless communication. The main constraint of the case study is the choice of weights of attributes of various networks. In order to resolve this issue, a new network selection algorithm which is based on weight estimation of the representative set of the network attributes is proposed using entropy and TOPSIS approach. The proposed model is effectively implemented to select the desired network in a heterogeneous environment of UMTS, WLAN, GPRS, and WiMAX employing triple-play services (Voice, Data and Video). The model selects the desired network in heterogeneous environment in accordance with the required QoS attributes (delay (D), total bandwidth (BW), packet loss (L) and cost per byte (CB)) for the application under consideration. On altering the attribute values of delay by 10% for voice users and 30% for video and data users, change in network selection occurs significantly. In addition to above, a novel method is proposed that takes into consideration user preferences (requested data rate, velocity, tolerable data loss), network

conditions (available capacity, coverage, expected data loss due to network overloading/network selection delay) and QoS (network selection rate, RSS, delay, jitter) in order to select the optimal network between WiMAX and 3G and achieves the best balance between user's requirement and network performance. It incorporates the use of parameterized network and user profiles in order to model diverse QoS flexibility for different real time (RT) and non-real time (NRT) applications. In the RT traffic case, the proposed scheme performs better as compared to RSS based scheme and Hungry scheme by at least 10% in terms of the data loss. The solution is realistic and not very complex to implement on mobile user units and other network elements.

In second approach, network selection in wireless heterogeneous environment based on available bandwidth estimation has been presented. We consider available bandwidth as a dynamic parameter to select the network in heterogeneous environment. We propose novel network selection algorithms capable of adapting to prevailing network conditions in heterogeneous environment of 3G & WLAN networks, 3G & WiMAX and WLAN & WiMAX in real time. We utilize a bootstrap approximation based technique to estimate available bandwidth and compare it with hidden Markov model based estimation to determine its precision. It is implemented in temporal and spatial domains to verify its robustness. Estimation error, overhead, estimation time with varying size of traffic and reliability are used as the performance metrics. Analysis of heterogeneous system reveals that the proposed network selection methods can effectively choose the suitable network by negotiating trade-offs among network dynamic conditions and multimedia services.

In third part, we propose algorithms for network selection based on the link parameters, assuming that network conditions are dominant in network selection. Network selection function (NSF) consists of averaged RSS, distance and outage probability parameters to perform network selection. It comprises of two stages. In first stage, overlapping region is identified through distance estimation. Network selection algorithm based on averaged received signal strength plus outage is invoked in second stage to select the optimum network between two different networks- GSM and UMTS. The predicted overlapped distance is utilized to make a network selection in order to minimize the probability of network selection failures or unnecessary selections from one cellular network to another. Significant reduction of 68% in network selection rate has been obtained with the application of proposed algorithm as compared to conventional method. In addition to above, another network selection algorithm utilizing signal strength, available bit rate, signal to noise ratio, achievable throughput, bit error rate and outage probability metrics as coefficient of cost function NSDF (Network Selection Decision Function) for network selection has been proposed. The selection metrics are hybridized with PSO for relative dynamic weight optimization. The proposed algorithm is implemented in a typical heterogeneous environment of EDGE (2.5G) and UMTS (3G). The proposed model based on dynamic metric weights optimized by modified PSO resulted in significant reduction of the network selection rate, computational complexity and time. Minimization of network selection rate while maintaining QoS for multimedia services is recorded, which in turn reduces the overhead on the MS. Proposed algorithm maintains QoS while selecting ABC network in heterogeneous environment by keeping utility function at least 0.5. The best possible QoS can be achieved when achievable throughput is greater than guaranteed required bandwidth or utility function is equal to 1. When network selection is performed by using proposed algorithm then utility function is always greater than or equal 0.5. It is very useful and applicable in supporting multimedia applications over wireless environment due its high convergence capability and simplicity. In continuation, another network selection algorithm is proposed on the same platform for a heterogeneous environment consisting of WiMAX and LTE standard. It is based on received signal strength, signal to noise ratio, available bit rate, achievable throughput and bit error rate. Relative weights of the decision making attributes are optimized employing particle swarm optimization approach. Satisfaction decision function (SDF) utilizes dynamic optimized weights to select optimal network in heterogeneous environment of cellular networks. The number of satisfied users calculated as per their demand with wireless network selected by proposed algorithm is optimized by modified PSO and affirmed by Monte Carlo method. It is observed that network selection rate is dependent on user motion. SDF based algorithm yielded 50% better performance in terms of the satisfied users as compared to existing techniques/algorithms.

The results of proposed approaches demonstrate that more parameters considered can influence the results in network selection and related QoS. It reduces unnecessary network selections and network selection failures, computational complexity, time and balances the network load with prefect utilization factor. At the end this could lead to the network, where users will be always and anywhere best connected with the desired QoS. Research findings show that the proposed schemes are suitable for implementation on smart mobile terminal available in the market. In future, there are possibilities to make profit from better utilized networks by the operators with more number of smart users/ multimedia users.

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GLOSSARY

2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
AABE	Adaptive Available Bandwidth Estimation
AISA	Autonomic Interface Selection Architecture
ANN	Artificial Neural Network
ABC	Always Best Connected
ABW	Available Bandwidth
ADR	Asymptotic Dispersion Rate
ASC	Always most Suitable Connection
AHP	Analytic Hierarchy Process
ANFIS	Adaptive Neuro Fuzzy Inference System
ANP	Analytic Network Process
ANS	Access Network Selection
ANS	Automatic Network Selection
AP	Access Point
ATS	Access Technology Selector
AV	Audio/Video
BcN	Broadband Convergence Network
BER	Bit Error Rate
BNS	Best Network Selection
BS	Base Station
CAC	Call Admission Control
CARD	Candidate Access Router Discovery
CDMA	Code Division Multiple Access
CFNS	Cost Function based Network Selection
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance

CUSUM	Cumulative Sum
EDGE	Enhanced Data for GSM Evolution
ELECTRE	Elimination and Choice Translating Priority
ESA	End point Service Availability
ETSI	European Telecommunications Standards Institute
FAHP	Fuzzy Analytic Hierarchy Process algorithm
FIS	Fuzzy Inference System
FLC	Fuzzy Logic Controllers
FL	Fuzzy Logic
FTP	File Transfer Protocol
FNN	Fuzzy Neural Network
FVIKOR	Fuzzy VIseKriterijumska Optimizacija I Kompromisno Resenje
DALSS	Dynamic Access Link Selection Scheme
DHD	Dynamic Handoff Decision
DNCBP	Dynamic New Call Blocking Probability
DSA	Dynamic Spectrum Allocation
DSS	Decision Support System
DVB	Digital Video Broadcasting
DST	Dempster-Shafer Theory
HA/CH	Home Agent / Cluster Head
HAWK	Heterogeneous Advanced Wireless Network
HIPERLAN	High Performance Radio Local Area Network
HSDPA	High Speed Downlink Packet Access
HWN	Heterogeneous Wireless Networking
IARD	Improved Access Router Discovery
IETF	Internet Engineering Task Force
IGI	Initial Gap Increasing
IMS	Integrated Management System
IP	Internet Protocol
GA	Genetic Algorithm

GAP	Generalized Assignment Problem
GM	Grey Model
GoS	Grade of Service
GRA	Grey Relational Analysis
GS	Generic Services
GSM	Global System for Mobile Communication
GPRS	General Packet Radio Service
3GPP	3rd Generation Partnership Project
3GPP2	3rd Generation Partnership Project2
LAN	Local Area Network
MAC	Medium Access Control
MADM	Multiple Attributes Decision Making
MATLAB	Matrix Laboratory
MBAC	Measurement Based Admission Control
MCDM	Multi Criteria Decision Making
MEW	Multiplicative Exponent Weighting
MIH	Media Independent Handoff
MGC	Multimedia Group Communication
MGRA	Modified Grey Relational Analysis
ML	Multi Link
MN	Mobile Node
MO	Multi Objective
MS	Mobile Station
MT	Mobile Terminal
MPEG-21	Moving Picture Experts Group – Multimedia Framework
MWFNSA	Modified Weight Function based Network Selection Algorithm
MWN	Mobile Wireless Networks
NANS	Network Assisted Network Selection
NAT	Network Access Technology
NBB-VoD	Neighbours Buffering Based - Video on Demand

NGWS	Next Generation Wireless Systems
NGN	Next Generation Networks
NMMD	Novel Method based on Mahalanobis Distance
NSF	Network Selection Function
OFDMA	Orthogonal Frequency Division Multiple Access
OPNET	Operational Network Evaluation tool
OSI	Open Systems Interconnection
OUSI	Overall User Satisfaction Improvement
RAN	Radio Access Networks
RAT	Radio Access Technology
REACH	Reflected Exponential Chirp
RNS	Radio Network Selection
RSS	Received Signal Strength
RTOPSIS	Rank Reversal Technique for Order Preference by Similarity to Ideal Solution
SA	Software Assistant
SAW	Simple Additive Weighting
SDF	Satisfaction Degree Function
SCV	Squared Coefficient of Variation
SIR	Signal to Interference Ratio
SIP	Session Initiation Protocol
SLA	Service Level Agreements
SLoPS	Self-Loading Periodic Streams
SNR	Signal to Noise Ratio
SINR	Signal to Interference plus Noise Ratio
SRSS	Sum Received Signal Strength
S^3	Smart Session Selection
T-DVHD	Trusted Distributed Vertical Handoff Decision
TISPAN	Telecommunications and Internet converged Services and Protocols for Advanced Networking
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution

QoE	Quality of Experience
QoS	Quality of Service
PoA	Point of Attachment
PHY	Physical Layer
PGM	Probe Gap Model
PVCS	Preference Value based Cell Selection
PSO	Particle Swarm Optimization
PRASO	Policy based Radio Access Selection and Optimization
PQoS	Perceived Quality of Service
PRM	Probe Rate Model
PPPT	Packet Pair Probing Technique
PTR	Packet Transmission Rate
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
UDP	User Datagram Protocol
UMADM	Uncertainly Multi-Attribute Decision Making
UMTS	Universal Mobile Telecommunications System
UIVH	User Specific Intelligent Vertical Handoff
UNI	User Number Increase
UPNS	User Preference oriented Network Selection algorithm
VCW	Variance Coefficient Weighting
VHDA	Vertical Handoff Decision Algorithm
VHDMA	Vertical Handoff Decision Making Algorithm
VHO	Vertical Handoff
VHONE	VHO Necessity Estimation
VIKOR	VIseKriterijumska Optimizacija I Kompromisno Resenje
WLAN	Wireless Local Area Network
WiBro	Wireless Braodband
WiMAX	Worldwide Interoperability for Microwave Access
WMN	Wireless Mesh Network

WPM	Weight Product Method
WRMA	Weighted Rating of Multiple Attributes
WSM	Weighed Sum Model
WPAN	Wireless Personal Access Network
WWAN	Wireless Wide Area Network
WWW	World Wide Web

ACRONYMS

γg	Path loss exponent for GSM
γu	Path loss exponent for UMTS
ξ_g	Shadow fading component of GSM
ξ_u	Shadow fading components of UMTS
σ_s	Standard deviation of shadow fading
σ	Standard deviations of shadow fading after taking average of signal strength measurements
ρ	Auto-correlation coefficient
χ_g	Zero mean independent wide sense stationary Gaussian random processes for GSM
χ_w	Zero mean independent wide sense stationary Gaussian random processes for UMTS
Γ	Received signal strength of wireless network
Γ_t	Threshold received signal strength
τ_i	Network selection latency time into region
τ_o	Network selection latency time out of region
Υ	Signal to noise ratio
ω	Inertia factor
δ	Constriction coefficient
η_i^{min}	Minimum acceptable bandwidth threshold
ξ	Tuned steepness parameter
τ	Distance dependent delay
λ_i	Traffic
θ	Average available bandwidth

θ_e	Random sample
Π	Initial state probabilities
λ	The model used to underpin the most likely sequence of states
λ_0	Initial model
Γ	Induced changes in traffic
$\lambda_{c,i}$,	The value of a factor of network i for category c
$\lambda_{c,\chi}$	The value of a factor of networks in χ set, for category c
λ_{ac}	Current traffic load level of the cell
$\lambda_{Cov,i}$	The coverage (i.e., network radius) of network *i*
$\lambda_{Cov,X}$	The coverage (i.e., network radius) of network *X*
η_b	Mean network boundary crossing rate
η_h	Mean handover rate
μ	User
$\tau_{rdr,\mu}$	Requested data rate by user μ
$\lambda_{E,i}$	Total expected data loss
$\tau_{v,\mu}$	User μ's velocity
$\tau_{v,\chi}$	A set of velocities of the existing users
$\lambda_{AvgSDR,i}$,	Average service data rate per user
$\lambda_{SoC,i}$,	Expected share of the capacity (SoC) the user will take at a network *i*
$\tau_{LeftFS,\mu}$	Remaining data sizes of the user μ
$\tau_{LeftFS,\chi}$	Remaining data sizes of other users in *X*

CHAPTER 1

INTRODUCTION

During the last few years, there has been increasing demand of multimedia applications over wireless networks. In the existing scenario of a wide range of radio access technologies, selection of the optimal network in heterogeneous environment is an important and challenging task for ensuring anytime, anywhere, and with any device, connectivity.

Initially, Second Generation (2G) cellular networks were designed primarily for voice communication based on circuit-switched technology. Later on, 3G networks were evolved to offer higher data transmission rate supporting 128 Kbps for a mobile user and 2 Mbps for fixed applications. In further evolution of 4G/Next Generation Networks (NGN) wireless technologies offered peak data rates of 100 Mbit/s for high mobility users and 1 Gbit/s for low mobility users. With the commercial deployment of 4G standards in 2011, the focus of the mobile research community is moving towards next set of innovations in wireless communication technologies resulting in "5G" (5th Generation technologies). As shown in Fig.1.1, with ten-year cycle for each generation of cellular advancement, it is expected that networks with 5G technologies will be deployed around the year 2020.

Within a fully interconnected world, the distinct relationship between users and service providers rapidly changes towards a scenario of collaboration and multiple users compete for access to the system. 'Ubiquitous', 'Convergence' and 'smart' are keywords describing future networks and applications [1]. The technological aspects of ubiquitous networking and communication technologies are including challenges related to network selection, seamless mobility, security, and trust.

In order to provide ubiquitous wireless access in the heterogeneous environment of networks with complementary characteristics, it is essential to integrate different radio access technologies under one umbrella. In such Heterogeneous Wireless Networks (HWNs) integration, development of an efficient and reliable network selection algorithm has been an important and challenging research problem towards ensuring seamless communication for multimedia applications along with acceptable QoS [3].

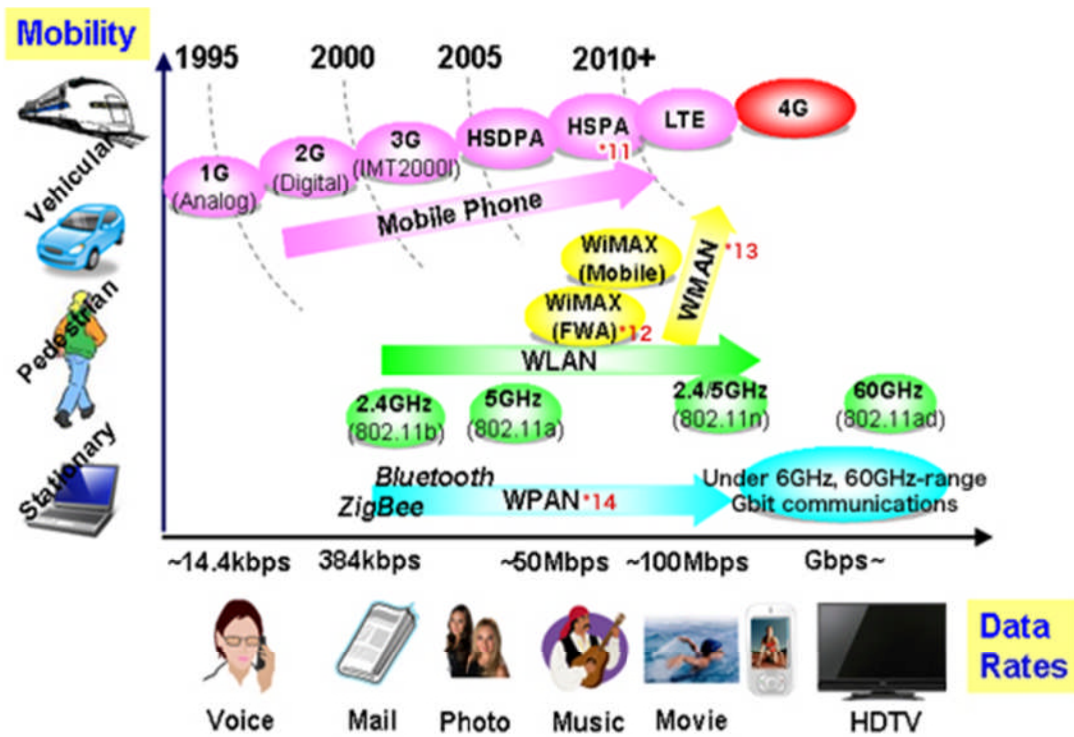


Figure 1.1: Evolution of wireless communication systems [2]

Users with multi-interface terminals are able to initiate connectivity through the access technology that the best suits their attributes and the requirements of their applications. The main advantage of HWN lies in its ability that users can maintain their sessions when moving across different networks. This enables users to continuously select the most appropriate network during their communication. For network operators, HWN paves the way to higher profitability through more capable networks where complementary advantages of individual technologies are combined [4]. For example, EDGE (Enhanced Data for GSM Evolution) network supports upto 384 Kbps over a wide geographical area while UMTS (Universal Mobile Telecommunications System) cellular networks can provide upto 2 Mbps in a smaller coverage area.

The objective is to offer seamless multimedia services to users accessing all infrastructures through heterogeneous access technologies. IP (Internet Protocol) is supposed to perform as an adhesive for providing global connectivity and mobility among networks [5]. Network selection is a critical aspect of NGN for seamless communication. There are three main issues regarding network selection in NGNs as mentioned below.

The first issue deals with optimal choice of access technology. User may access the network through multiple radio access interfaces. An overlay network is supposed to choose the radio access technology suitable for the services that the user is accessing. There are numerous complementary technologies existing today as shown in Fig 1.2. WLAN is the best suitable technology for high data rate indoor coverage with lower degree of mobility. GPRS or UMTS, on the other hand, are preferred for nationwide coverage and can be regarded as wide area network, providing high degree of mobility. Therefore a user of the mobile terminal or the network needs to make the optimal choice of radio access technology among all those available. A handover algorithm determines which network to connect to as well as when to perform a handover between different networks, assuring the best possible wireless link. The network selection strategy should take into consideration the type of application being run by the user at the time of handover. This offers stability as well as the best possible available bandwidth for interactive and background services.

The decision of the mobile device on the suitability of the network can be based on network bandwidth, signal strength or certain policies stored in the user's profile. For example, a user may use WLAN while streaming a video or might switch to GPRS while listening to highly compressed audio.

The second issue is concerned with the design of a mobility enabled IP networking design, which has the functionality to deal with mobility between access technologies. This includes fast, seamless vertical (between heterogeneous technologies) handovers (IP micro-mobility), quality of service (QoS), accounting and security. Real-time request in the future will require fast/seamless handovers for smooth operation.

The third issue deals with contemporary multimedia consumer devices which are increasingly obtaining network connectivity mostly through wireless medium. In order to economically support the mobile lifestyle of users, a new class of multimodal consumer devices has emerged that are equipped with heterogeneous wireless access capability.

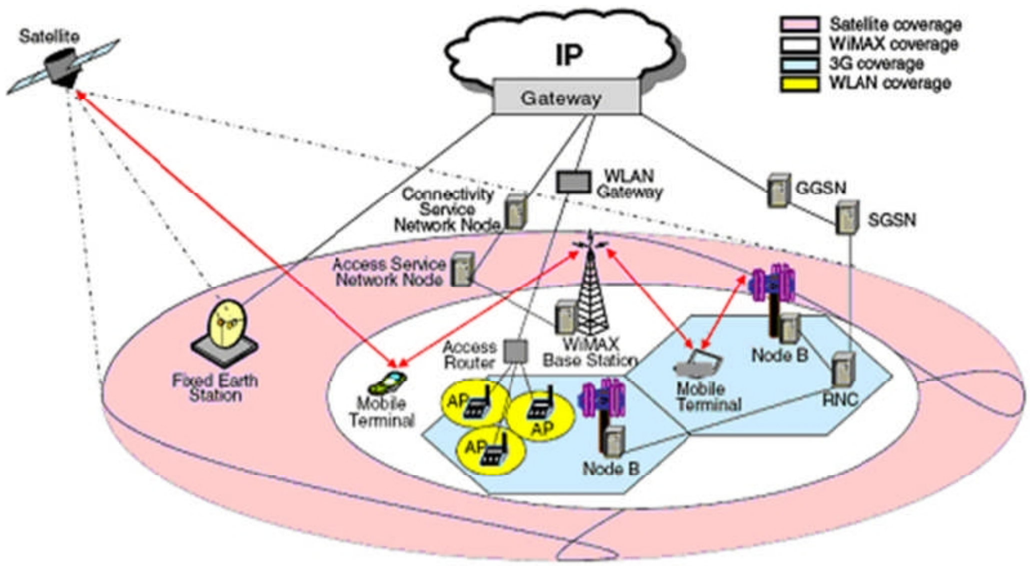


Figure 1.2: An example of heterogeneous wireless network architecture. [6]

Inter-working of heterogeneous packet switched wireless networks, e.g., cellular and WLANs, via IP is a key step to provide ubiquitous service delivery via seamless connectivity of consumer devices. These wireless networks have a diverse range of capabilities and therefore selection of a specific network to optimize service delivery is an issue [7] Indeed multimedia will be the main service feature of NGNs, and changing radio access networks may in particular result in drastic changes in the network state. Consequently the structure for multimedia transmission must be adaptive. For example, in cellular networks such as UMTS, users contend for limited and expensive bandwidth. Variable bit rate (VBR) services provide a way to ensure service provisioning at lesser cost. Besides, the radio environment has dynamics that renders it difficult to provide a guaranteed network service. This necessitates that the services are robust and adaptive against varying radio situations.

Problem of network selection across heterogeneous wireless networks has recently received much attention because of a drive for converged communication systems. In this research work the major emphasis is given on network selection criteria for multimedia services in heterogeneous wireless network environment.

NGNs give users several options when they need to initiate a session or connection. With vertical handoffs feasible, selecting the most appropriate network for the user becomes persistently possible and not just at session initiation. The core of network selection, as shown in Fig 1.3, is essentially a trade-off between user policies and profile on one hand and operator policies on the other.

User policies dictate requirements based on user's contract, applications and terminal capabilities, in addition to behavior profile comprising of mobility, application frequency, etc. User preferences may specify the verbal description of expected QoS, monetary readiness, seamlessness, service availability, etc. Terminal abilities include radio interfaces type, quality, radiated power, presentation capabilities speakers, display, codec and loaded protocol set. Application requirements are in general may be defined in terms of the metrics including bit error rate, bandwidth, jitter, and encryption level. The final consideration from the user's perspective is the user's profile, which includes attributes such as current position relative to available networks in the overlay, mobility, type of applications etc.

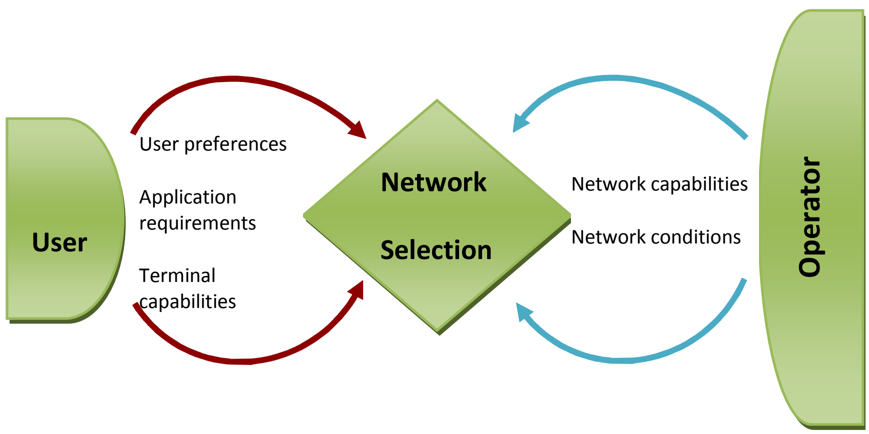


Figure 1.3: Elements of network selection. [8]

On the operator's side, network selection depends on operator's objectives. The operator, for example, could be interested in load balancing and may direct users accordingly. If the user is within the coverage of more than one network, the operator would also consider the capabilities of the different networks. For various reasons, the capabilities of the different networks under an operator may momentarily change in terms of available services, coverage, QoS, consistency or even cost. In terms of policies, in addition to load balancing, the operator may be interested in dictating the type of services delivered through the operator's network or the type of terminals that can be serviced in a certain access technology. The complexity of network selection hence depends on the number of considerations taken into account. At the crucial level, if a certain network is the best given a certain attribute X, and the same element is the most important for the user, then the user will be associated with this very network whenever possible [8].

1.1 Motivation and significance of research

Seamless mobility across heterogeneous wireless networks is an important research problem and challenging aspect towards realization of the concept of 'always best connected (ABC)' user device. Though, significant research has been done to achieve seamless mobility, there are still some unaddressed issues such as weight estimation criteria for network selection parameters, impact of user's velocity, number of satisfied users after network selection, reduction in unnecessary network selections and network selection failures, contemplation of dynamic parameter such as available bandwidth for network selection of multimedia users and maximizing utilization, which need to be considered. In order to assuring the acceptable quality of the currently running service, proper weight assignment of QoS related parameters is one of the most important task. Most of the existing multi-criteria schemes are assigning different weights to network selection parameters to prioritize network selection according to the application. Most of the time, the assignment of these weights is done randomly without considering any criteria for weight estimation of a certain network parameter. This could lead to a degraded performance if one parameter is given higher weightage as compared to another, especially during an ongoing user session, such as a Voice over IP (VoIP) conversations, where attaining a minimum level of QoS is essential. Thus, estimation of the correct weights of network parameters is an important task while moving in a heterogeneous wireless environment.

Many of the existing network selection algorithms, which are based on single metric such as Received Signal Strength (RSS), do not exploit the benefits of multi-criteria and the inherent knowledge about the sensitivities of network selection parameters in a heterogeneous wireless environment. In addition, while performing network selections, these algorithms do not take into account the QoS of an ongoing session to maximize the end-user's satisfaction based on their location, preferences, and/or application contexts.

The present research is focused on the important aspects of network selection for the processing of seamless mobility. Network selection decisions are typically performed based on more than one network's parameters, including, but not limited to RSS, security, MS velocity, cost, available network bandwidth, latency, battery status of MS, power consumption, and user preferences. These decisions often incorporate network-operator's policies and end-user's preferences as well. Automating network selection decision in a heterogeneous environment is a complex task due to several reasons. For example: varying network characteristics, mobility patterns, and environmental conditions etc.

The network selection can be divided into initiation and target network selection. Most of the available research work deals with the target network selection, ignoring the two important parameters: initiation and need of selection. Initiation and the necessity of estimation play a critical role in maximizing end-user's satisfaction. Just like the values of weights associated with network parameters, the calculations to perform necessity estimation and target network selection are usually performed using random values of parameters provided by different networks, without paying much attention to the information contained therein.

In addition, our expectation of connectivity will increasingly include personalized service enrichment. These enhancements will influence context information associated with the device, applications, services and the user. We assume that improvement in the connectivity experience will stimulate innovation in new services and devices that will further enrich our lives beyond what we can envision today.

Future mobile networks are expected to be all-IP based heterogeneous networks that allow users to use any system anywhere and anytime. They consist of a layered arrangement of diverse access technologies, e.g. WLAN, WPAN, UMTS, WiMAX, which are linked via common IP based core network to provide inter-working. These networks are expected to provide high usability, support for multimedia services, and personalization. Key features are user friendliness and personalization as well as terminal and network heterogeneity. User friendliness refers to the way the user interacts with the terminal, which must be friendly and simple. User personalization indicator sends to the way users configure the operational mode of the terminal based on personal inclinations. Given the huge spectrum of existing users with experiences, different preferences and background, the effect is that user friendliness and personalization should be able to offer a high degree of granularity such as the huge amount of information, is selected in an appropriate way.

Nowadays, multimedia services are gaining momentum worldwide. Although there has been a proliferation of new wireless technologies that provide enormous bandwidth, still multimedia streaming applications suffer from limited bandwidth. Mobile devices are being designed as multi-homed, multi-functioning wireless terminals to exploit the maximum throughput of the heterogeneous network model [9].

Multimedia data transmission experiences a number of constraints that results in low Quality of Service (QoS) offered to the end user. These are mainly due to the nature of multimedia applications, which are characterized by the properties- the demand for high data transmission rate (bandwidth-consuming applications i.e 4Mbps in MPEG2), the sensitivity to packet delays (tolerable 0.25 sec), latency (tolerable 150 ms) and jitter (tolerable 5 sec)) and the tolerance to packet losses (<< 1%) for packet loss tolerant applications [10], when compared to other kind of applications. In wireless networks multimedia data transmission inherits all the characteristics and constraints related to the propagation to the free space. Most striking difference between wired and wireless networks is the cause of packet losses. Packet loss in wired networks take places mainly due to congestion in the path between the sender and the receiver, while packet losses in wireless networks occur mainly due to corrupted packets as a result of the low Signal to Noise Ratio (SNR), the multi-path signal fading and the interference from neighboring transmissions.

Mobility feature in wireless communication introduces a number of additional barriers in multimedia transmission. These initiate new design challenges to the networking world as it is in fact difficult to combine guaranteed high bit rates and an acceptable packet loss ratio with low latency and jitter.

All the above factors have motivated both the research community and the industry to develop and propose a number of new protocols and optimization techniques targeting at mitigating delay and packet loss ratio during the transmission of multimedia information. On the whole these efforts are based on the classical layered approach in which the various layers try to optimize its performance by adapting its behaviour to constantly varying network parameters and provide its best services to upper layers. Under this layered approach, communication occurs between two adjacent layers without taking conversely into deliberation the specific characteristics of multimedia applications. Though the layered approach has been the fundamental factor for the growth of the wired networks and the World Wide Web (WWW) it seems to pose serious constraints when attempting to adapt protocol's behaviour to multimedia application characteristics and to wireless network conditions. These are some of the unattended issues which need further investigations. All these challenges motivated us to undertake the proposed research work.

In the present research work, we have undertaken the following major research objectives:

1.2 Research objectives

- To study the existing network selection criteria for heterogeneous wireless networks for multimedia applications.
- Development of a new algorithm for network selection of heterogeneous wireless networks.
- Performance evaluation of the proposed algorithm.
- Comparison of proposed algorithm with existing algorithms.

1.3 Methodology

Network selection in heterogeneous wireless networks is different from homogenous networks, which solely relied on RSS. When heterogeneous networks are involved, the consideration of RSS only is not enough due to the random nature.

In heterogeneous wireless environment, certain wireless technologies are more suitable for specific types of services. Thus, new network selection methods must include traffic-specific or network-specific characteristics of heterogeneous wireless networks. In order to fulfill this need, we propose three algorithms based on QoS parameters, available bandwidth estimation and link parameters as shown in Fig. 1.4. The proposed research work is focused on network selection algorithms in wireless heterogeneous environment, while user runs multimedia services. Network selection between heterogeneous networks depends on various policies. Selection in heterogeneous wireless networking environments is a complex process and requires energy as well as time in order to accomplish seamless mobility. It is obvious that this procedure needs to be carefully handled for efficient vertical handover execution and achieving optimal resource management.

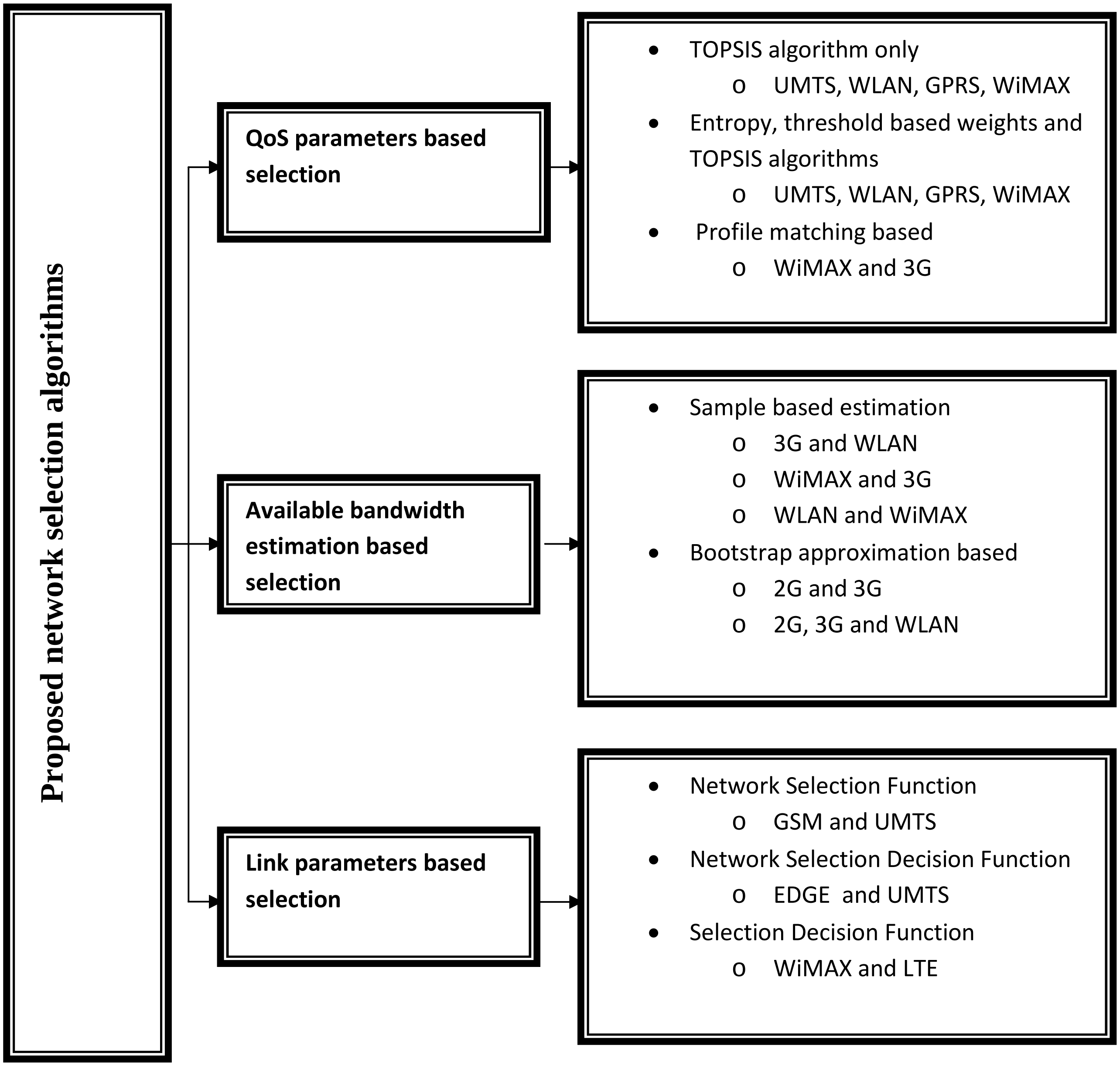


Figure 1.4: Proposed network selection algorithms

In general network selection can be performed by physical events referring to the network interface availability and by user profile, policies and preferences. The decision criteria are indicators of whether or not a selection is needed. The criteria could be coverage, bandwidth, latency, link quality, user profile, battery power, velocity, cost, security level, QoS parameters etc. A criterion helps to choose the best network and decision policy represents the influence of the network on where and when the selection occurs. A complete analysis needs to take into consideration to recommend required parameters to perform network selection. In this work the following set of selection parameters has been adopted:

- Link parameters (RSS, SNR, Throughput, Available bit rate, Total bandwidth, Packet loss, Bit Error Rate (BER), Delay, Outage probability)
- Mobility aspects (distance, speed and velocity)
- Type of service and requested QoS (network selection rate, RSS, delay, jitter)
- Available bandwidth estimation of networks in heterogeneous environment
- User’s profile / preferences (requested data rate, velocity, tolerable data loss, endurable cost)
- Network profile (available capacity, coverage, expected data loss due to network overloading/network selection delay, Cost per byte)

The link parameters of the network have weightage, which represent relative importance of the links for network selection. Another aspect is the mobile users or other fast moving vehicles as it is important to analyze the mobility aspect. When the user is on the move, there is a higher risk of being disconnected or transferred to other networks frequently, which is referred to as ping-pong effect. QoS requested by the user depends upon application running either in real time or non real time. However, the user might tolerate the slight degradation of QoS under certain circumstances, when the available networks characteristics/profiles constraints also hold significant importance.

Another main consideration is dynamic parameter calculation for real time multimedia applications e.g. Internet banking, streaming etc. Here, we considered the available bandwidth to select the target network. If the user has lower bandwidth than expected, then available bandwidth plays crucial role while making network selection decision. For example, if the user runs the real time application, such as a video call, if the user needs to select another network, user might lose the connection.

User profile characteristics and network profile capabilities will greatly influence network selection, which is the next logical step after network discovery. We examine the dynamic network selection paradigm that uses network profiles and user profiles to rank networks for selection using profile matching algorithm.

Performance of proposed algorithms is evaluated in terms of cost effectiveness, sensitivity of receiver, network selection failures, utilization factor, number of satisfied users, network selection rate, network selection delay, reliability, estimation error, overhead, data loss, and throughput by applying real time and non real time multimedia applications e.g. streaming, voice, file transfer, video calling etc.

1.4 Thesis organization

The organization of this thesis is as follows. Chapter 2 provides a brief introduction to the network selection process, followed by a comprehensive overview of the related work. In Chapter 3, QoS based network selection scheme is proposed. Available bandwidth estimation based network selection scheme is presented in Chapter 4 and Chapter 5 presents link parameters based network selection algorithms. Finally, Chapter 6 concludes this research work along with outline of the future research scope.

1.5 Summary

In order to meet the requirements of the mobile users, a heterogeneous wireless environment integrates different access technologies with dissimilar characteristics. In such a diverse environment, the requirement for ubiquitous service delivery is usually equivalent with the Always Best Connected problem, i.e., the selection of the access technology that best suits the needs of the users. It is thus an important research problem to devise mechanisms for selecting the optimal network for given user. The network selection decision may be based on several QoS parameters that ought to be optimized. This makes the network selection process a very difficult task. In the present work, we have undertaken the network selection problem and make attempt to propose the solution in heterogeneous wireless networks supporting multimedia applications.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, comprehensive literature review on selection of wireless network in heterogeneous environment for multimedia services is presented. It highlights noteworthy achievements of some previous research works and identifies issues and research gaps in the related area.

2.2 Network selection process background

2.2.1. Classification of network selection methods: Every decision mechanism needs to get information of relevant factors as inputs. These inputs are vital in order to make a high quality decision; referring to the nature, these can be separated into two categories: predetermined and time varying. The predetermined factors are enumerated priori and stay for a long period of time whereas time varying ones alter with time. Initial policy or preferences are considered as predetermined factors. These also include constraints of application and capabilities of technology and equipments; in contrast, time-varying factors are monitored continuously. Examples of both categories are given in Fig. 2.1. After having information about factors, various decision making techniques are deployed in management schemes that give the best possible solution for service providers. Usually these determine best access technology and point of attachment for new and ongoing connections. Decisions are enforced afterward by mechanism such as admission control.

2.2.2. Desirable features of network selection: Fig. 2.2 [11] describes several desirable features of network selection algorithms as mentioned in the literature [11,12]. Some of these features are described below:

- ***Number of network selections:*** It is defined as the number of selections mobile station experiences while moving from one network to another. It needs to be minimized to reduce the overhead on the mobile unit and network under consideration.

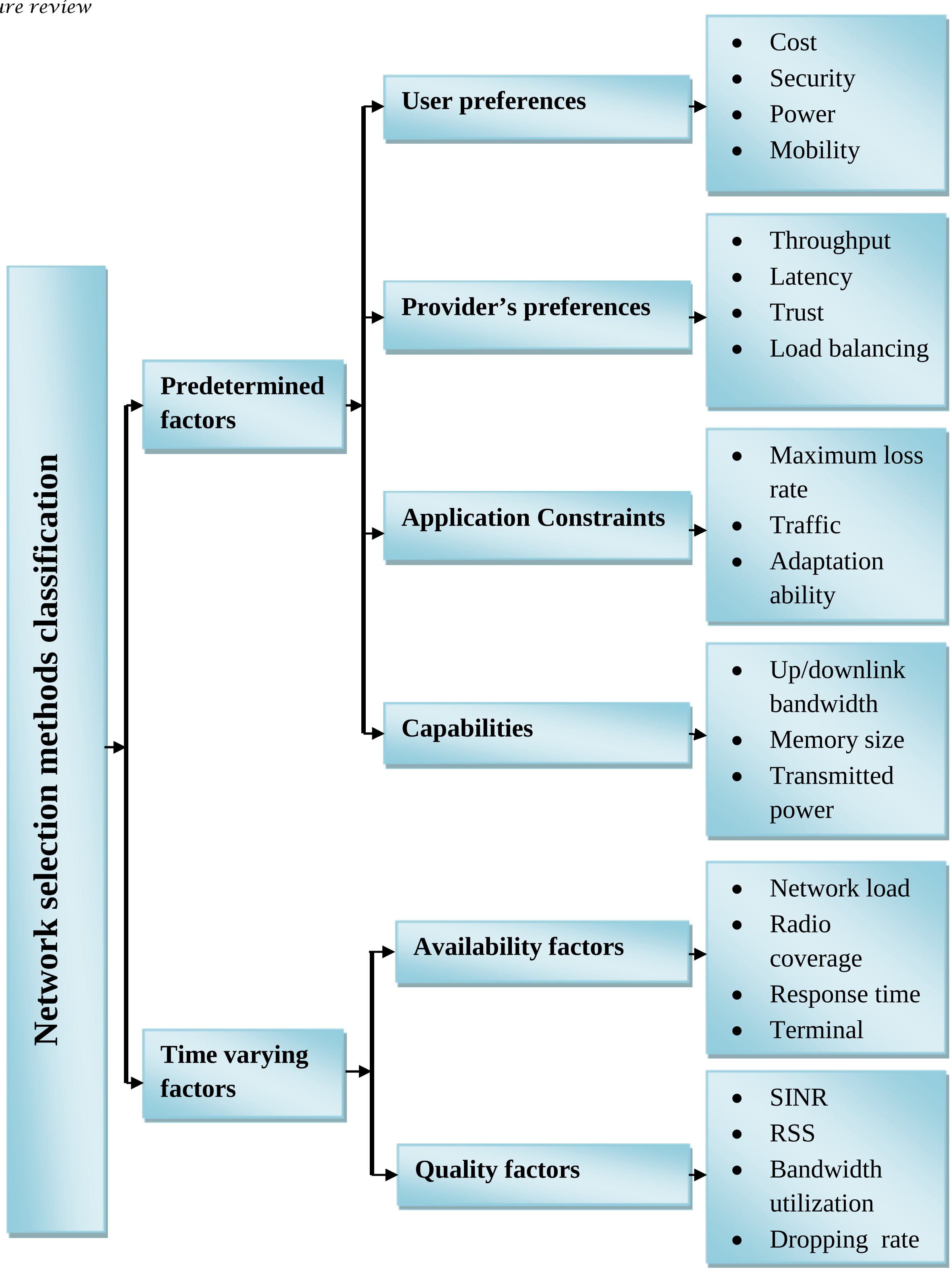


Figure 2.1: Criteria of network selection

- ***Overhead:*** Number of network selections enhances the signaling overhead. It will further affect the capacity of the link. So it needs to be minimized to optimize the performance of heterogeneous wireless network environment.

- ***Interference:*** Wireless systems are interference limited. It is one of the most critical parameters in network selection process for next generation wireless networks due to frequency reuse factor. Interference conditions gain a significant attention in network selection decision making process and hence need to be minimized to improve system performance.
- ***Reliability:*** This provides information about the robustness of the selection algorithms in providing handoffs.
- ***Utilization:*** It is a measure of current utilization of the access network or the wireless link. It can be expressed in percentage. It is desirable to maximize the utilization of the available network resource.
- ***Number of satisfied users:*** It is the foremost requirement of the network selection criteria that it must satisfy the maximum number of users with their selections.
- ***Performance:*** While performing network selection it is desirable to maintain the performance of network as well as user in term of QoS and GoS.
- ***Seamless mobility:*** Seamless mobility is the ability for users to remain connected while roaming across different networks. It gives the users access to mobile content with automatic switching between protocols, communication channel, physical environment, connectivity across local, wide and personal area networks and offers

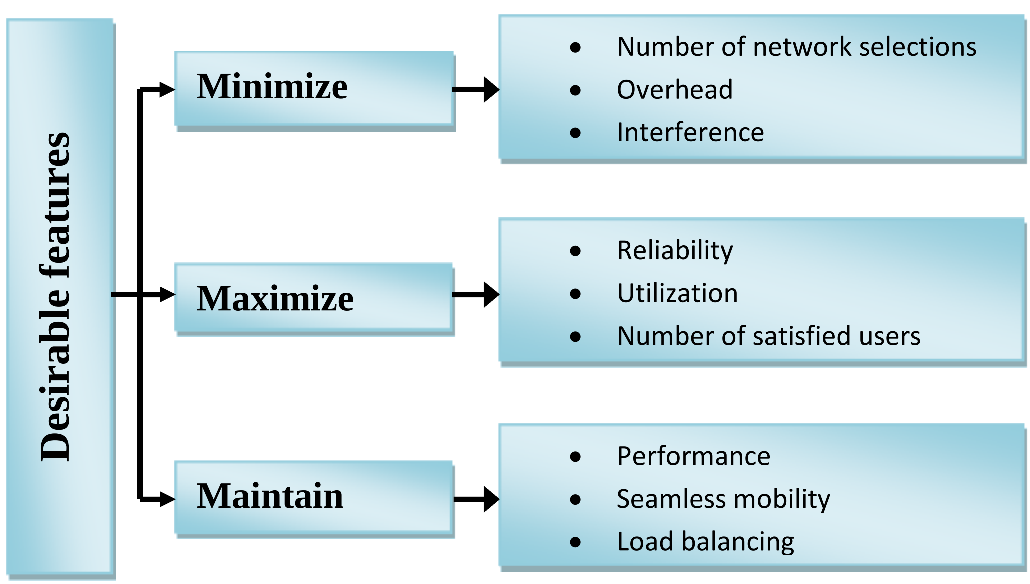


Figure 2.2: Desirable features of network selection

seamless access. It allows the users to roam across home, car, office, airports, hotspots, campus and beyond without interruption.

- ***Load balancing:*** Load balancing is a process to control and manage the system in the way that users can achieve guaranteed QoS. The role of load balancing metric in network selection algorithms is to describe the load situation of the system accurately in terms of utilization of the shared resources.

2.2.3. Network selection metrics: Fig. 2.3 [11] and Fig. 2.4 [13] describe several network selection metrics that are used as inputs to various selection algorithms. These metrics are described below:

- ***Received Signal Strength (RSS)*****:** This criterion is simple, direct, and widely used in network selection algorithms. This is easy to measure and is related to the QoS of an application. Also, RSS is inversely proportional to the distance between the MS and the BS, and could result in excessive and/or unnecessary selections.
- ***Signal to noise ratio (SNR):*** SNR is the ratio of the signal power to the noise power. It is measured in dB (decibels).
- ***Bit error rate (BER):*** It is the probability of bit errors divided by total number of transmitted bits of cellular network present in heterogeneous environment.
- ***Total Bandwidth (TB):*** This characteristic is a measure of the overall bandwidth of the wireless access; e.g., 11 Mbps for IEEE 802.11b.
- ***Available Bandwidth (AB):*** This feature is a measure of the bandwidth allowed by the access network on per user basis; e.g., 200 Kbps. It will be based on access network operator policies and can also change dynamically based on service level agreements or network utilization level. Measured in bits/sec (bps), available bandwidth is used to determine traffic load conditions of network and is a good measure of available communication resources at the base station.
- ***Achievable throughput:*** It is the amount of data moved successfully from one place to another in a given time period [14]. It is measured in bits per second (bit/s or bps).
- ***Available bit rate (ABR):*** It depends on the channel bandwidth (BW) and SNR of cellular networks present in heterogeneous environment.

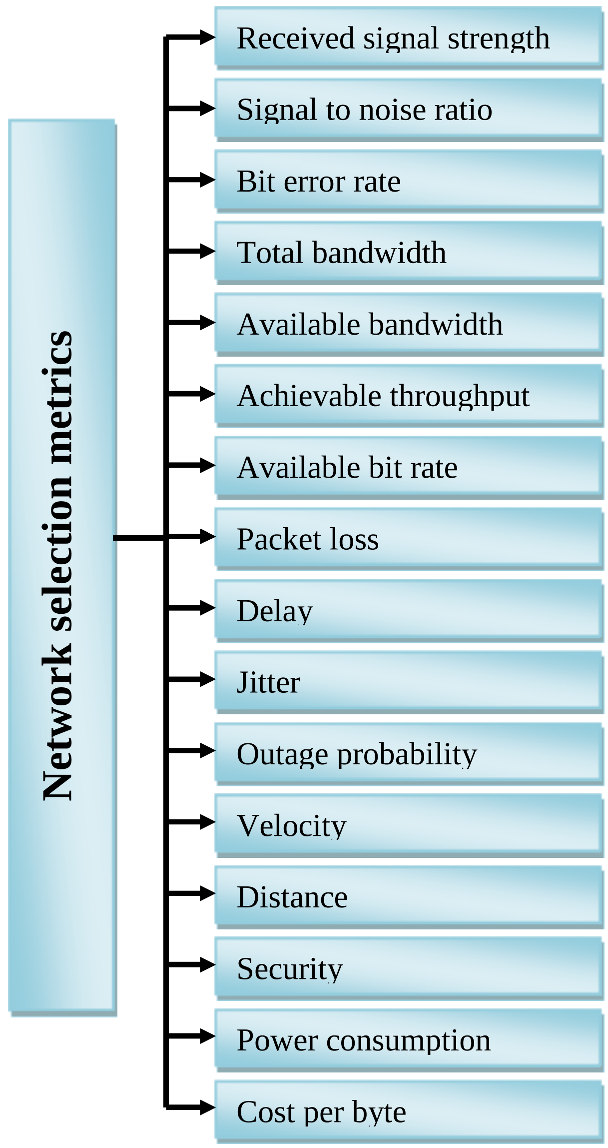


Figure 2.3: Network selection metrics

- ***Packet Loss (L)***: This feature is a measure of the average packet loss rate within the access system over a considerable duration of time. It can be expressed in packet losses per million packets or percentage values.
- ***Delay (D):*** This measures the average delay variations within the access system. It may be measured in milliseconds.
- ***Jitter (J):*** It is defined as a variation in the delay of received packets. It may be measured in milliseconds

- ***Outage probability:*** It is described as the probability, where the averaged RSS is less than a certain threshold.
- ***Velocity*:** Velocity is an important decision factor as it relates to the network connection duration metric and location of the MS. An MS travelling at a very high speed may result in excessive selections between wireless networks.
- ***Distance:*** It is as another selection parameter used to identify the overlapped region for network selection in heterogeneous environment to reduce burden on MS.
- ***Security*:** Certain applications require confidentiality, and/or the integrity of the transferred data to be preserved. This metric can be used to handoff to a network that offers higher security as compared to other available networks.
- ***Power Consumption*:** Network selection process demands a fair amount of power consumption. If an MS were running low on battery power, it would be preferable to select a target network that would help extend the MS's battery life [11].
- ***Cost per Byte (CB):*** This characteristic is a measure of the operator's transport cost for a particular access network type. It can be measured in relative or absolute terms (e.g., in percentage or dollars/byte). Different operators may operate heterogeneous wireless networks and may have varying costs associated with them. The network with the least cost should be a preferred target for selection.

2.2.4. Performance evaluation metric of network selection algorithms: The performance of different network selection algorithms can be evaluated and compared on the basis of following metrics:

- ***Network selection Delay*:** This metric represents the time elapsed between the network selection initiation and completion. The complexity of the network selection algorithm has a direct effect on this metric; a simple algorithm results in a smaller value of this metric. A smallest possible value of selection delay is desired for delay sensitive and real-time applications.
- ***Network selection rate*:** It is defined as the expected number of selections MS experiences while traversing a trajectory from one network to another. This performance measure represents switching load associated with the network selection process.

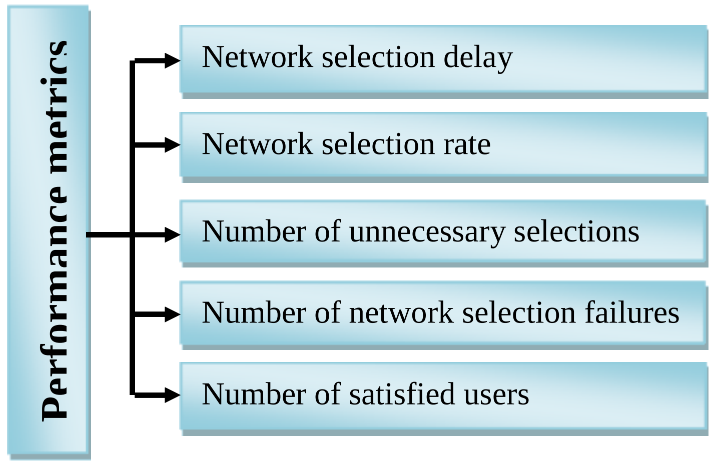


Figure 2.4: Performance evaluation metrics of network selection

- ***Number of unnecessary network selections:*** Unnecessary network selections should be minimized as these waste network resources and increase processing overheads.
- ***Number of network selection Failures*****:** A network selection failure occurs when the target network fails to allocate sufficient resources for the MS that is handed over from a previous network. This failure is also possible when a moving MS goes out of the coverage area of the target network before the completion of the selection process. This metric affects the quality of service of an ongoing session.
- ***Number of satisfied users*****:** It is calculated according to the completion of user's respective demand from the selected network.

2.2.5. Existing network selection algorithms: Due to the ever existent demand for always best connectivity, seamless mobility, network selection has always been an area of intense research, and is likely to remain so in future due to diversification and integration of heterogeneous wireless networks. During the literature review, following network selection algorithms were explored. These techniques are classified as shown in Fig 2.5.

2.3. Related work

In this section, the literature on network selection in wireless heterogeneous network in several aspects is presented. Common challenges namely decision mechanism, QoS support and mobility support as well as related issues is identified.

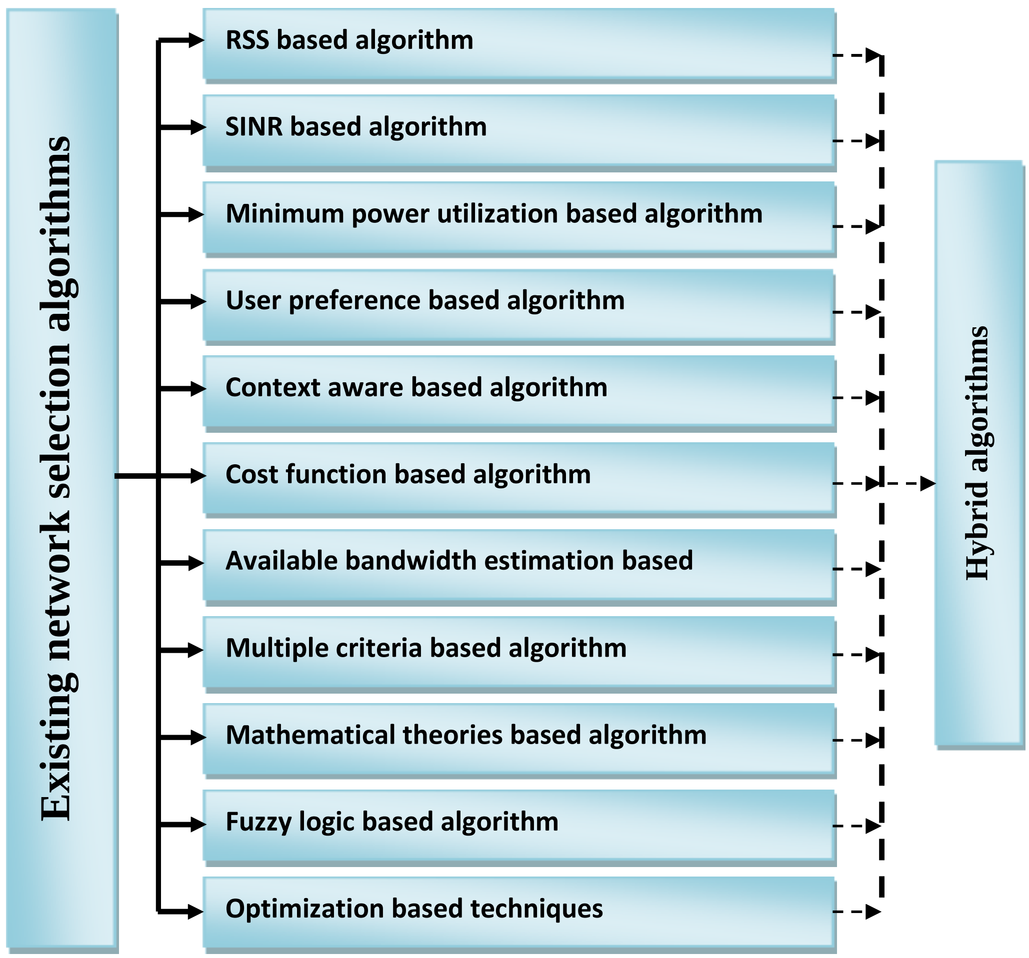


Figure 2.5: Classification of existing network selection methods

2.3.1. RSS based algorithms: Network selection is the decision process for a mobile terminal to handover between homogeneous or heterogeneous networks. This handover decision can be either mobile or network initiated. Conventionally decision is mainly based on the RSS. In this approach, the RSSs of the different available networks are measured over time and the BS or AP with the strongest signal strength is selected to carry out a network selection. A number of studies [15-19] have been conducted in this area due to the simplistic nature of this approach. Since heterogeneous wireless networks contain different wireless technologies, their RSSs cannot be compared directly, and thus relative RSS does not apply to network selection decisions. On the other hand, other network parameters such as bandwidth, cost, delay etc. are typically combined with RSS when making decisions for network selection. It is important to mention that the possible signal fluctuations due to multipath fading can result in the undesirable ping-pong effect, i.e., unnecessary network selections that increased the probability of call failures and drops during the network selection.

Earlier, in [20] an empirical formula for handover/network selection rate as a function of base stations separation, path loss exponent, standard deviation of shadow fading, averaging distance and correlation distance was proposed. The handover initiation algorithm was based on averaged signal strength measurements using relative signal strength with hysteresis margin approach. The proposed formula was applied to optimize the performance of handover initiation under varied propagation environments. In addition to the previous one, an initiation network selection algorithm based on the combination of position location of mobile terminal and the absolute signal strength thresholds was proposed in [21]. Global System for Mobile communication (GSM) and UMTS networks were considered for creating heterogeneous environment. This algorithm reduced the handover/network selection rate by around 50% and thus improved the network resource efficiency as compared to that based on signal strength thresholds only. In order to improve the performance, a dynamic decision model to decide the best network at the best time moment to handoffs was proposed in [22]. It was based on dynamic factors such as RSS of network and velocity of mobile station simultaneously with static factors like usage expense, link capacity (offered bandwidth) and power consumption. This model met with the individual user needs and improved the whole system performance by reducing the unnecessary handoffs.

Authors in [23] focused on a handoff triggering/network selection criterion based on RSS, distance information and context information such as the dropping probability, blocking probability, Grade of Service (GoS), and number of handoff attempts. The velocity threshold as a decision making criterion was determined to optimize the system performance. To assign the available channels to the mobile stations the optimal velocity threshold was adjusted using four handoff strategies.

The continuity of wireless services and enhanced communication quality was guaranteed by soft handover mechanism introduced in [18]. Hysteresis-add and hysteresis-drop were considered as the Soft handover parameters. The performance of CDMA cellular system was characterized in terms of mean active set size and soft handover region. The above parameters have decisive effect on performance metrics. The performance of network selection further enhanced with adaptive soft handoff algorithm introduction in [24]. It dynamically calculated the soft handover margin based on the RSS and distance. Performance was estimated in terms of active set update rate i.e. soft handover region, active set size and probability of outage. Adaptive soft handover algorithm showed better performance as compared to that of fixed soft handover margin in varied propagation conditions. Determination of soft handover probabilities as function of soft handover threshold (*Tadd* ~ *Tdrop*) was presented in [25] for different network scenarios while considering constant speed motion of MS and also achieving a guaranteed QoS.

Exploiting traveling distance prediction method, handover necessity estimation mechanism proposed in [26] used distance threshold parameters to avoid unnecessary handovers. It kept the probabilities of handover failure and unnecessary handover close to the predetermined designed values. For network selection the predicted RSS of neighbor networks and dwell time metrics were considered in [27]. To perform selection early, the RSS was predicted by back propagation neural network whereas dwell time value dependent on moving pattern and user speed. For triggering a handoff, the RSS conditions were required consistently true during dwell time, so that unnecessary handoffs were avoidable. The predictive RSS and current RSS conditions have different policies for real time and non-real time services in different networks. Policies in the merit function were presented to select an optimal network. In the merit function, the weighting factors were dynamic to neighbor networks. Network selection outperformed the other approaches by performing handoff earlier and reducing the number of handoffs, connection dropping, GoS while increasing the average utilization per call.

2.3.2. SINR based algorithms: Signal to Interference Ratio (SIR) is typically used to measure the quality of communication. The effects of SIR and carrier to interference ratio (CIR) were demonstrated in [28]. In this approach, a network selection is initiated if the SIR of the current Point of Attachment (PoA) is lower than the threshold. In [29], researchers proposed a vertical handoff algorithm which used received Signal to Interference plus Noise Ratio (SINR) from various access networks as the network selection criteria. Algorithm considered the combined effects of SINR from different access networks with SINR value from one network being converted to equivalent SINR value to the target network, so that the selection algorithm can have the knowledge of achievable bandwidths from both access networks to make handoff decisions with QoS consideration. The improvement of overall system throughput using SINR based vertical handoff is evident as compared to the RSS based vertical handoff. Also, in contrast to the traditional algorithms, the method proposed in [3] took ambient interference power, which was referred as an interference rate, as an input to the decision process. The results showed that the performance was considerably enhanced for both user and network by it. In same sequence one more strategy based on the estimated SINR value in an integrated heterogeneous wireless network for network selection was considered in [30]. It allowed users to select the network that has a higher SINR value from all the available networks during its communication. In comparison with other strategies in the literature, it was found that it performed better than RSS only, but worse than traffic based network selection in terms of blocking probabilities of calls. In [31] multi-attributes SINR based vertical handoff algorithm for next generation heterogeneous wireless networks with predictive SINR using Grey Model (GM) (1, 1) was proposed. It utilize the combined effect of SINR, user traffic cost, user required bandwidth utilization and user preference to make QoS aware handoff decision. The problem of handoff request triggering was handled by using (GM (1, 1)). It was a first order forecasting technique having one variable to predict the subsequently SINR value. If it was lower than a pre-specified threshold, handoff request was fired. The proposed algorithm performed better in terms of higher system throughput, user satisfaction and less cost to user traffic.

2.3.3. Minimum power utilization based algorithms: Today's mobile terminals are being designed as multi interface nodes [32], which result in increased number of physical interfaces yielding increased energy/power consumption. It limits battery capacity. Therefore, the network selection in heterogeneous environment must be an energy aware entity. It must consider the energy consumption while selecting an access network, hence preserving the needed QoS for the active sessions. Another reason is that the multimedia streaming to battery powered mobile devices has also become extensive. Though, the battery power capability has not kept the pace with the advances in other technologies and due to this it is rapidly becoming a major concern. Multimedia applications are known to be high energy consumers and the battery lifetime is an important factor for mobile users. While keeping this into consideration, some authors proposed energy/power efficient network selection algorithms. As energy efficient handovers scheme with geographic mobility awareness was considered in [33]. It used the geographic mobility feature of mobile devices. By eliminating unnecessary handovers, reducing the number of network scanning and avoiding too frequent interface switching, the proposed scheme significantly conserved the energy of mobile devices due to handover. The research work in selection [34] proposed the use of network's transmission power as a handoff criterion. The proposed technique attempts to find a pair of networks with available channel that has a SIR based on minimum transmitted power. It reduced call dropping probability, but increased the number of unnecessary handoffs. A network selection algorithm considering power consumption in hybrid wireless networks for vertical handover was proposed in [35]. CDMA, WiBro, WLAN networks were candidate networks for this selection algorithm. It was combination of the power consumption prediction algorithm and the final network selection algorithm. The expected lifetime of the mobile station based on the traffic class, current battery level and power consumption for each network interface card of the mobile station was estimated by the power consumption prediction algorithm. If the probable lifetime of the mobile station in a certain network was not long enough as compared to the handover delay, that particular network was removed from the candidate network list. It prevented unnecessary handovers in the preprocessing procedure. In contrast, the final network selection algorithm consisted of Analytic Hierarchical Process (AHP) and Grey Relational Analysis (GRA). The global factors of the network selection structure were QoS, cost and lifetime. If user preference was lifetime, then proposed algorithm selected the network that stays longer due to low power consumption. A network selection algorithm whose network selection decision based on the estimated energy consumption was proposed in [36]. It enabled the multimedia stream to last longer while maintaining an acceptable user perceived quality by selecting the least power consuming network.

2.3.4. User preference based algorithms: These approaches considered in [37- 42] mainly take into account the end user's preferences in terms of MS's power consumption, associated service cost, offered security, and the QoS provided by a candidate network. Most of these approaches are developed to maximize the end user's satisfaction while utilizing real and non real time applications. For this purpose, Best Network Selection (BNS) architecture was introduced in [43]. The design goals of BNS architecture were simple, efficient, flexible and fully considered user preferences. In accordance with the context of services and user intention middleware architecture supporting efficient seamless connectivity with service management was proposed in [44]. The contexts associated with the Vertical Handoff (VHO) process and service management was defined in terms of profiles. With implementation of the proposed scheme, the number of unnecessary VHOs and application failures were drastically reduced, leading to an improvement of around 34% in data throughput. The approach also reduced application failures by 50% and the number of VHOs by 32%.

A preference value based cell selection (PVCS) scheme to satisfy QoS requirements, minimize handoff occurrence frequency, and maximize accommodated number of calls in heterogeneous wireless networks were proposed in [45]. The PVCS scheme is divided into three stages: cells selection of candidate, calculation of preference value and target cell determination. The candidate cell's selection was used to shift the suitable cells for the call request. All appropriate cells make a candidate cell set. The preference value calculation computed the preference value of each cell in the candidate cell set, which was optimized by considering QoS factor, mobility factor, and loading factor, for the purpose of maximizing accommodated number of calls, minimizing handoff occurrence frequency and maintaining QoS requirements of a call request. Eventually, the candidate cell which had the maximum preference value was selected for the call request. PVCS scheme achieved higher throughput while satisfying the QoS requirements.

User satisfaction metric based network selection considered the network response time for serving the decision making requests in [46]. Such a framework was important for guiding the relocation of mobile terminals to achieve offloading. Additionally, an analytical model for the computation of the user satisfaction was introduced, based on the work reported in [47]. The analysis used multiclass queuing networks to model the requests to the network as transactions among the system entities and computed the user satisfaction and network response time bounds. The global bounds on the asymptotic network response time and throughput per class were affected by the number and frequency of reconfiguration decision requests. The analysis quantified the increase in the automaticity level of mobile devices affects the network load and maximize the percentage of requests handled by the network in comparison with percentage of dropped requests. The degree of performance deterioration was caused by increasing the automaticity level in the management of requests. To implement user preferences as per the features of 4G, a network selection algorithm was proposed in [48]. Rank based on distance function computed for various available services/access technologies. Weighted distance function was obtained from multiple QoS parameters as per user needs.

Another effective and efficient scheme was investigated in [49] to dynamically select the most appropriate network path according to user preferences such as cost, speed, quality and capacity among heterogeneous networks. A Modified Weight Function based Network Selection Algorithm (MWFNSA) that considered user preferences and application profiles were proposed in [50]. It has considered the characteristics of both network conditions and connection performance in deciding the weight functions of the network.

2.3.5. Context aware based algorithms: The approaches presented in [51-57] use context information to perform intelligent handoff decisions. Contextual changes are also taken into account to determine the necessity of network selections. Context information is collected from the following:

- ***Mobile Station:*** Capabilities, remaining battery power, location, and velocity.
- ***User*:** User's preferences in terms of preferred network usage cost, security, and desired QoS.
- ***Candidate Network*:** Provided QoS, available bandwidth, security offerings, latency, coverage area and cost of usage.
- ***Application*:** QoS requirements based on the type of service (Conversational, Background, and Streaming, etc.) needed.

Authors in [58], investigated all type of information to form the network selection algorithm based on context-awareness integrated with the Quality of Experience (QoE) or the Perceived Quality of Service (PQoS) by the user. It was shown to be dependent on the user requirements and reduced the decision delay in network selection by reducing the number of the targets for different class of service features and improved the user perceived quality. Another algorithm for a context-aware network selection was proposed in [59] based on a modified Weight Product Method (WPM) for access network selection. A weight distribution method was used based on sensitivity analysis of WPM for the most influential criteria based on the state of user at a given time.

2.3.6. Cost function based algorithms: The cost function based approaches [60-68] combine different system's metrics in a cost function that represents a measure of the benefit obtained by selecting a particular candidate network. For every candidate network, the sum of weighted functions of specific parameters is evaluated to produce the final cost of the network. In this context, a dynamic and user-centric network selection and decision process across heterogeneous networks was proposed in [69]. A Satisfaction Degree Function (SDF) was used as a cost function to select the best one from available networks according to user's predefined criteria. The criteria considered user policies and information from several Open System Interconnection (OSI) Layers, including application requirements and dynamic network status.

Moreover, the establishment of conviction relationships between fourth generation wireless networks entities poses a major challenge to provide seamless communication. In this regard, exchanging trust information between networks and mobile nodes is an important factor which guarantees a trusted network selection. In [70], a Trusted Distributed Vertical Handoff Decision (T-DVHD) scheme was presented which provided trusted and seamless vertical handover. The T-DVHD performed well in terms of handoff delay, blocking rate and throughput. A cost function designed using monetary cost, power consumption, and network load parameters in [71] to choose the best available access network while taking the end-user's preferences on various variables into account. Another Cost Function based Network Selection (CFNS) strategy was proposed in [72], which considered a user's needs in an integrated wireless and mobile network. The proposed network selection strategy affected multiple system parameters viz. blocking probability of originating calls and the forced termination probability of handoff calls, which needs to be handled carefully. In [73], authors investigated the use of one more cost function to perform an optimal network selection using information provided by wireless network standards (such as network coverage map or network properties). The cost function provided flexibility to balance different factors in the decision making, improving both seamlessness and energy efficiency of the device and handovers. It selected the optimal networks and triggered handovers at appropriate times to increase overall network connectivity as compared to traditional triggering schemes, while at the same time optimizing energy consumption of multi-radio devices.

Considering the user's services satisfaction, a network selection algorithm based on dynamic weight setting was proposed in order to solve the existing problems that there is not a tradeoff between user's preferences and network conditions. A possibility based Uncertainly Multi-Attribute Decision Making (UMADM) method was used for handoff cost function in [74]. The network selections adopted Always most Suitable Connection (ASC) principle in order to utilize the wireless sources efficiently. The proposed algorithm improved the whole QoS performance of services, and enhanced the cost effectiveness of the selected networks.

Improved Access Router Discovery (IARD) a network discovery and selection method was proposed in a heterogeneous environment comprising of WLAN and UMTS networks [75]. A special Weighted Mean (M_W) cost function algorithm used with which each network rank based on several criteria and the highest rank network was selected as the target network. This method was tested under various conditions and different traffic types and resulted in more appropriate network selections as compared to other methods. A scalable and flexible network selection scheme for multi-service heterogeneous wireless networks was proposed in [76]. Profiles were generated for users or cells to represent their characteristics in three categories (traffic status, mobility and QoS). The best cell was determined for each user via profile matching. The proposed scheme utilized the information available from the underlying wireless technologies. It handled the interplay between multi-service traffic classes more effectively than existing schemes. The traditional network selection based on utility/cost function only considered few factors and had limited use in multimedia applications. A utility based scheme was proposed to work in the future urban road heterogeneous wireless networks [77]. It considered more key factors such as utility functions regarding QOS and energy saving, threshold calculated from a utility function, consideration of the load balance, user's preferences and the handoff stability which are crucial for multimedia communication.

A flexible cost (utility) function was introduced in [78] to decide the access alternative with a preferred operator while selecting the link with the most excellent quality amongst others or minimizing the number of handovers. Afterwards, it was used to study a set of access selection strategies to establish the permutation of parameters which might lead to optimum performances. A cost function named Dynamic New Call Blocking Probability (DNCBP) was introduced in [79] to make handoff decision for heterogeneous wireless networks. With the application of this simple and fast algorithm, mobile nodes did not experience service degradation or interruption. The proposed algorithm outperformed the traditional approach in terms of handoff dropping rate, bandwidth utilization rate and handoff rate.

Network selection and handoff decision with the goal of maximizing user Quality of Experience (QoE) based on cost function named Dynamic Handoff Decision (DHD) was investigated in [80]. It was based on Q-learning and chose the best network based not only on the current network state but also the potential future network and device states. In contrast to other dynamic programming based algorithms, this method did not require the knowledge of the statistics of the wireless environment, but learned an optimum policy by utilizing the mobile device's past experience. QoE results of the proposed algorithm came very close to the performance of an optimum oracle algorithm. Fewer number of network handoffs were required on an average. A Media Independent Handoff (MIH) cost function based Call Admission Control (CAC) for vertical handoff in a loosely coupled Mobile Wireless Networks (MWN) was proposed in [81]. The cost based CAC modeled the resource occupancy of each wireless network in a MWN as a Markov chain model at BS and then formed a cost-reward CAC for maximizing network reward. In MS, the vertical handoff scheme adopted a predictive RSS to predict the moving trend of mobile stations to select the optimal target network. Numerical results indicated that this approach outperformed other approaches in GoS and the number of vertical handoffs while yielding competitive utilization. An adaptive network parameter prediction algorithm, which established the prediction function for each network parameter and computed the network's QoS was proposed in [82]. Then the handoff process based on network parameter prediction was presented to guide the handoff execution. The handoff decisions based on real value and prediction value were compared in the WLAN inter-network environment. The proposed prediction model eliminated the unnecessary handoffs which were caused by the performance limitations of the access network, predicted evolution trends of the network parameters in the case of performance gradual change and made the terminal connect to the QoS ensured network as soon as possible.

2.3.7. Available bandwidth estimation based algorithms: The available bandwidth in a network path is of major importance in congestion control, QoS verification, streaming applications, server selection, and overlay networks [83-84]. The quality of available network connections can often have a large impact on the performance of distributed applications. For example, File Transfer Protocol (FTP), Gopher and the World Wide Web (WWW) applications suffer increased response times as a result of network congestion. The document transfer time is directly related to the available bandwidth of the connection in these applications. Available bandwidth depends on the underlying capacity of the path from client to server. It is limited by the bottleneck link and the amount of other traffic competing for links on the path. If the value of these attributes is known to the application, the current utilization of connections can be computed. Network utilization is used as a basis for selection from a set of alternative connections or servers. If available servers change frequently, then dynamic server selection scheme becomes important in a mobile computing environment. In order to provide these measurements at the application level, two tools have been introduced viz. bprobe - which provides an estimate of the uncongested bandwidth of a path; and cprobe - which gives an estimate of the current congestion along the path. These two parameters are used in combination to provide the application with an estimate of available bandwidth between server and client thereby enabling application-level congestion avoidance [85]. The ability to measure metrics such as link bandwidth is essential, but the power of measurement models and techniques must keep pace with the size and complexity of the Internet. In [86] a deterministic model of packet delay called packet tailgating, to measure link bandwidth along a path through the Internet has been presented. Prototype implementation showed that it placed a lesser load on the network than previous measurement techniques while maintaining similar accuracy. But the tailgating technique depends only on the existence of store-and-forward routers. To improve the existing methods, a network friendly bandwidth measurement method, TOPP, was introduced in [87]. It was based on active probing. Contrary to traditional packet pair estimates of the bottleneck link bandwidth; it was able to detect bottlenecks that were invisible to methods such as C-probe.

The effect of the size of the probing packets was investigated by [88] and also showed that the conventional wisdom of using maximum sized packet pairs was not optimal. As the length of the packet train increased, there was a significant reduction in measurement variance. The converged value referred as Asymptotic Dispersion Rate (ADR). It was lower than the capacity. The effect of the cross traffic in the dispersion of long packet trains was clearly evident. Putting all the pieces together, presented a capacity estimation methodology that has been implemented in a tool called path rate. Initially probing gap was a critical parameter when using packet pairs to estimate available bandwidth. Based on this insight, [89] presented two available bandwidth measurement techniques, the Initial Gap Increasing (IGI) method and the Packet Transmission Rate (PTR) method. These techniques estimated available bandwidth faster than existing techniques such as Pathload, with comparable accuracy. The measurement accuracy of active probing is affected by factors such as length of probing packet train, probing packet size and contending traffic on links other than the tight link. Based on the concept of self-induced congestion, an active probing tool pathChirp for estimating the available bandwidth on a communication network path was presented in [90]. It offered several significant advantages over existing probing schemes based on packet pairs or packet trains. It used only packets inter arrival times for estimation and did not require synchronous and highly stable clocks at the sender and receiver. It offers good estimation of the available bandwidth while using only a fraction of the number of probe bytes than state of the art techniques used.

A probing method called a minimal backlogging method was also proposed to estimate the available bandwidth. Statistics based on the service rate of minimally backlogging probing traffic for queuing system. The proposed mechanism could estimate the available bandwidth quickly and track it adaptively. Available bandwidth obtained using the mean and variance of the estimated available bandwidth in a multiple hop network topology [91].

End to end available bandwidth measurement called Self Loading Periodic Streams (SLoPS) was implemented in Pathload tool [92]. Pathload is non-intrusive, as it did not cause significant increases in the network utilization, delays, or losses. The available bandwidth became significantly more variable in paths with limited capacity as well as in heavily utilized paths. PathMon, an active probe method implementation was presented in [93], which required no prior knowledge of the network and no management control over the network to provide an end to end measurement of available bandwidth. In contrast to other available bandwidth methods, PathMon provided more accurate measurement across a range of bandwidths and converged more quickly with less overhead due to require considerably less traffic. In contrast to the previous methods in [94], the middle one packet in a tri packets probe was prioritized to measure both the output time gap and waiting time of the probe and improved the accuracy of the utilization measurement. It was also sensitive to the variance of traffic. All the existing estimation techniques and tools can be grouped into two classes. The first is Probe Rate Model (PRM), also known as Iterative Probing. The second is Probe Gap Model (PGM), also known as Direct Probing. Compared to the PRM, which requires multiple iterations with different probing rates, PGM uses a single probing rate and infer the available bandwidth from the relationship between the input and output rates of probing packet pairs. In [95], it was proved that PGM is accurate for multihop path under the case of path persistent for cross traffic, but PGM was accurate only as long as the input probing rate was set properly. PGM based available bandwidth estimation methods request the "busy assumption". Probing packet pairs should be in the same busy period when transmitted on bottleneck link, which was hard to satisfy especially for the low utilization path. So a bandwidth adaptive method was introduced to adjust the input probing rate. In [96], authors presented a new probabilistic methodology to estimate available bandwidth under non busy assumption and also proposed a metric to weigh the busyness of a network path based on the distribution of output probe gap. Using the metric, new methodology and previous methodology were combined to present a new available bandwidth estimation method called Adaptive Available Bandwidth Estimation (AABE) which was fit for both low utilization and high utilization paths. Compared with previous methods, it showed its advantages in terms of accuracy, overhead, and also the robustness when confronted with non-persistent cross traffic in multiple hop situations.

Although several techniques and tools have been developed to produce reliable estimations in real-time but it still remains challenging. It is essential to ensure that the measurement process is accurate, non-intrusive and robust to nondeterministic delays or traffic bursts [97]. An active probing tool called ASSOLO was presented for estimating available bandwidth based on the concept of self-induced congestion. ASSOLO featured a new probing traffic profile called Reflected Exponential Chirp (REACH), which tested a wide range of rates being more accurate in the center of the probing interval. ASSOLO outperformed pathChirp measurement tool and estimating available bandwidth with greater accuracy and stability.

Available Bandwidth of a link is the key metric for network design, management and selection. Several tools for available bandwidth measurement are presented in the literature and these provide satisfied results when used over wired networks. However, their performance over wireless links was not as good as in wired networks. The rapid deployment of wireless networks in various environments necessitates the development of new end to end tools that monitor and measure the properties of wireless paths well. Adhoc Probe was proposed as path capacity estimation tool specially designed for the multi-hop ad hoc wireless environment by [98]. A performance assessment of four tools (Clink, Pathrate, Pchar, CapProbe) carried out over wireless link for capacity measurement in a semi-anechoic chamber by [99]. The measurement station was designed to guarantee channel stationary and interference free measurement conditions and the performance assessment took advantage of a proper reference value for the measurand, which was obtained from physical layer measurements. The experimental analysis highlights that the performance of the tools was strongly dependent on the characteristics of the network interface cards.

A Packet Pair Probing Technique (PPPT) was adapted by [100] for the available bandwidth estimation of the wireless network. It was a well-known mechanism for measuring the capacity of an end to end path without any information of network routers. The cross traffic and the capacity variation of wireless link were considered to estimate the available bandwidth. With the development of broadband systems, multimedia communication in wireless networks has become very common. However, supporting multimedia applications over multiple users either require high bandwidth or a dynamic bandwidth utilization mechanism. This in turn calls for an efficient technique, that can estimate the available bandwidth in the network accurately over real-time. In [101], the different estimation algorithms were analyzed and key characteristic found was that all the bandwidth estimation techniques themselves consume some amount of bandwidth, which not only results in inaccurate estimation, but also take up precious bandwidth resource. This brought about the necessity for an intelligent probing technique that offsets the inaccuracy resulting from the self-use of the bandwidth, but also minimizes the bandwidth used by the probing mechanism.

It gives insight into how the capacity of a wireless path changes in real wireless environments. Streaming high quality audio/video (AV) from home media sources to TV sets over a WLAN is a challenging problem because of the fluctuating bandwidth caused by interference. To address this problem, an online application layer bandwidth measurement method was proposed that run at the sender application and used the differences of packet send times and feedback receive times [102].Video transmission needs stable sending rate in order that video displayed must have uniform qualities. In addition, lower packet loss rate is rather helpful in reducing video quality degradation. Consequently, reliable available bandwidth estimation becomes an indispensable step towards robust transmission of multimedia data. Precise estimation is impossible, because the existing available bandwidth estimation methods cannot deal with the false estimation problem. In [103], proposed a reliable available bandwidth estimation method based on distinguishing queuing regions and resolving false estimations. It obtained available bandwidth precisely, no matter the network environment either single-bottleneck or multiple-bottleneck. In [104], researchers investigated a light-weight probing method for available bandwidth measurement in a queuing analysis approach. A light weight probing technique infers the available bandwidth along a path without congesting the routers along the path, unlike the self congestion based measurement approach. It provided good estimates of the Squared Coefficient of Variation (SCV) of the probing stream regardless of the stochastic behavior of the arrival process of the cross traffic.

Authors in [105] proposed a one way delay jitter based scheme for available bandwidth estimation named 'JitterPath'. It exploited one way delay jitter and accumulated queuing delay to predict the type of a queuing region for each packet pair. In addition, quantify the captured traffic ratio, which defined as the total output gaps of joint queuing regions per total input gaps, and used it to derive the relationship between probing rate and available bandwidth. It also investigated the impact of the estimation resolution and the probing noise ratio on the accuracy of available bandwidth estimation.

In order to achieve a better understanding of the performance of current bandwidth measurement techniques in general traffic conditions, [106] presented a queuing-theoretic foundation of single hop packet train bandwidth estimation under bursty arrivals of discrete cross-traffic packets. The statistical mean of the packet train output dispersion and its mathematical relationship to the input dispersion, analyzed by using the probing response curve. The response curve deviation vanished as the packet-train length or probing packet size increases, where the vanishing rate was decided by the burstiness of cross traffic. Packet pair dispersion techniques are the most common probing based approach to measuring the bottleneck capacity of a path. Approximately all the existing packet pair techniques depend on heuristic filtering methods to find a final capacity estimate. In [107], developed a queuing model to describe the output packet pair dispersions interfered by the cross traffic to estimate the available bandwidth. The statistics of the cross traffic, e.g. the marginal distribution and the auto covariance function of the arrival process, also inferred from the stochastic behavior of the output packet dispersions.

Available bandwidth estimation methods have been proposed by various authors. However, the network scenarios and metrics used in the evaluations are limited and their analysis about the applicability of the tools in real network applications seems to be hard. An additional issue is that these evaluations do not include the amount of experiments needed to provide statistically valid conclusions. Authors in [108] proposed new available bandwidth estimation method with considerations of Broadband Convergence Network (BCN) where one could make use of quality guaranteed service. When customers were connected with each other through the best effort network as well as BCN, it was hard to guarantee QoS over the best effort network. Therefore, it was necessary to estimate accurate end to end available bandwidth to support end to end QoS. To address this issue, measurement performed on the terminal equipment. Additionally, the concept of the proportional share of link capacity was used for estimating available bandwidth.

In the wireless network, the network terminal often cannot dynamically select the best path to access the network due to the absence of the detailed network parameters. It will reduce the performance of the network. In [109] proposed a new Dynamic Access Link Selection Scheme (DALSS) based on the real time network state. The estimation of available bandwidth and capacity of each link were required to fulfill the link selection and alternation. The efficiency and availability of DALSS are evaluated in terms of throughput. A simple, yet efficient method to estimate the available bandwidth in WLAN and WiMAX networks to evaluate the real time status of the overlay networks and made a handoff decision based on the information was presented in [110]. A handoff process is not only triggered by unaccepted signal strength but also by unsatisfied QoS parameters. The proposed scheme kept stations always best connected with their QoS requirements met. QoS aware path selection scheme was proposed in [111], which estimated required bandwidth ratio. It is based on the QoS requirements of target service and the SINR of each path. The proposed scheme selected the optimal path which satisfied the QoS requirements among many heterogeneous wireless networks that changed dynamically. It supported multiple path selection as well as single path selection.

A hidden markov model based technique is used to measure end to end available bandwidth and monitoring. This estimation was implemented in a new tool called Traceband, which was found to be as accurate as Spruce and Pathload but considerably faster, and introduced far less overhead. Additionally, in comparison of using bursty cross-traffic, Traceband is the only tool that accurately reacts to zero-traffic periods. It is particularly useful for those applications that need to make decisions in real time [112].

In 4G wireless world, multihome mobiles have hardware capability to access heterogeneous wireless networks. Before initiating vertical handoff in these multihomed mobiles, it is required to estimate the available bandwidth in the heterogeneous neighboring networks. This estimation of available bandwidth minimizes handoff decision time. This mechanism of bandwidth estimation uses mobile agents. These are software programs, which perform computation on its move to the next node in the network. A mobile agent based bandwidth estimation mechanism was proposed in [113]. The mechanism was applied for two cases of handoff calls: connectionless and connection oriented services.

2.3.8. Multiple criteria based algorithms: This approach is based on a typical MADM problem where the selection of an access network is performed based on multiple attributes measured from all available candidate networks. Some of these MADM techniques are discussed as follows:

• ***Simple Additive Weighting (SAW)***: SAW is the best known and widely used scoring method utilized by [61, 114-119] to rank candidate networks. A weighted sum of all the network attributes is used to determine the overall score of each candidate network. The score of the candidate network is obtained by adding the normalized contributions from each metric multiplied by the weight assigned to the metric. The selected network has the highest score.

• ***Multiplicative Exponent Weighting (MEW)***: In these techniques [114-115, 120], a network selection decision matrix is formed. A particular row and column corresponds to the candidate network and attribute of that network placed. The weighted product of the attributes is used to determine the score of the network.

• ***Techniques for Order Preference by Similarity to Ideal Solution***: The selected network in the TOPSIS schemes [114-116, 121-125] is the one that is closest to the ideal solution and the farthest from the worst case solution. This ideal solution is obtained by using the best value for each metric. This technique can be applicable to problems spaces for the attributes with monotonically increasing or decreasing levels of utility. The algorithm calculates perceived positive/negative ideal solutions based on the range of attribute values available for the alternatives. TOPSIS based optimal network selection algorithm in wireless heterogeneous environment was presented in [126]. The wireless networks in this model represented the alternatives, while the network parameters (quality of service level, available bandwidth, security level, data transfer cost) were considered as the criteria for determining the optimal network. The TOPSIS algorithm has been validated by applying it on variety of cases as a compensatory MADM algorithm [127]. Application of the mechanism to networks with multilevel Service Level Applications (SLAs) has been described. In [128], the TOPSIS method was again used to select the best available network with performance metrics minimum handoff signaling delay and QoS parameters of the wireless applications specified by 3GPP. The causes of ranking abnormalities in TOPSIS were analyzed in [7]. As a solution it was also possible to consider it for decision making, where only the top ranking alternatives were important. But the proposed iterative TOPSIS approach applied to the problem, to remove the bottom ranked candidate network after each iteration. A hybrid ANP and RTOPSIS model to rank the candidate networks was proposed in [129]. ANP elicit weights to compensatory criteria and RTOPSIS resolved the rank reversal problem which happened in some multiple criteria decision making (MCDM) algorithms such as AHP, ELECTRE and TOPSIS.

The wireless networks in [130] represented the alternatives, whereas the network and application parameters (bandwidth, RSS, velocity support, power consumption and load factor, cost) were considered as the criteria for determining the optimal network. It was based on a decision process using the TOPSIS method when solving the multi criteria analysis. However, most of the previous works considered the access network selection process as a static optimization problem which failed to address the dynamic QoS conditions intrinsic in wireless networks. For network selection rating method developed called Weighted Rating of Multiple Attributes (WRMA) was used to evaluate the relative importance of the network attributes designated in [131]. The TOPSIS was applied to executing ranking process. Suitable network selection technique for heterogeneous wireless environment based on TOPSIS method was proposed in [132]. The network parameters (QoS level, network conditions, cost of service, security level) were considered as the triggering criteria for determining the suitable network. The potential of entropy based TOPSIS model in optimal network selection process was observed.

• ***Elimination and Choice Translating Priority (ELECTRE)***: This is another scheme [115, 119, 124, 133] used to rank the alternatives. The authors in [133] utilize a reference vector of attributes as an ideal alternative to adjust the raw attributes of the candidate networks. A matrix containing the difference between the attribute values of this reference vector and other alternatives is formed, and normalized. The resultant matrix contains attributes that have a monotonically decreasing utility. Weights are assigned to each attribute to take into account their relative importance. Finally, the concept of concordance (measure of satisfaction) and discordance (measure of dissatisfaction) is applied during the comparison of each alternative network with others. A candidate network with the highest value of concordance index and the lowest value of discordance index was considered as the preferred network.

• ***Analytic Hierarchy Process and Grey Relational Analysis (GRA)***: The AHP [118-119, 123, 134-137] decomposes the network selection problem into several smaller problems and assigns a weight value to each of them. GRA [138-140] is then used to rank the candidate networks, and the network with the highest rank value is chosen. In [135], the authors proposed a combined application of AHP and Grey System theory to evaluate the user's preferences and service requirements, and combined the QoS requirements with the candidate network's performances to make the final network selection decisions. Network selection model which based on the AHP and GRA methodology was introduced [141]. The best radio interface determined automatically without any user interaction by considering the user profiles and available networks & QoS parameters, for a given service. Analytical measurements were taken to analyze network selection algorithm in a realistic network environment. A network selection scheme for an integrated cellular and wireless local area network (WLAN) system to guarantee mobile users to be always best connected was developed in [142]. The proposed scheme applied an AHP to decide the relative weights of evaluative criteria set according to network condition, user preferences and service applications and calculated decision making index. The proposed network selection technique effectively decided the optimum network through making tradeoffs among user preference, network condition and service application, while avoiding frequent handoffs. In [143], the use of MCDM based on AHP for enabling a user being always best connected with regards to a set of criteria reflecting the needs of a Generic Service (GS). MCDM and AHP were typically used for management and business decisions in which the human aspect was involved to determine the importance between different criteria and alternatives. Different criteria for different GS and conditions made a difference regarding the decision based on performance, cost and accessibility ratings. Weights were derived for network selection by using GRA in [144]. It was used to evaluate the packet switched networks in terms of high QoS.

The scheme proposed in [145] integrated Variance Coefficient Weighting (VCW) and Modified Grey Relational Analysis (MGRA) for network selection in heterogeneous system with UMTS and WiMAX. The proposed network selection method effectively chooses the suitable network through making trade-offs among network dynamic condition and service application, at the same time avoiding frequent unnecessary handoffs. In order to evaluate the subjective weights in an efficient and automatic manner for network selection, a weighting method named TRUST was proposed in [146], which considered as an extended usage of the eigenvector and AHP method, but only specific for the network selection issue. The HWN environment composed of Bluetooth, WLAN, WiMAX and UMTS wireless networks where AHP was used to evaluate the weights and MCDM algorithms (i.e. SAW, MEW, TOPSIS and GRA), were used for network ranking in [147].

AHP and TOPSIS method were combined in [148] to propose an effective access network selection algorithm for heterogeneous wireless networks. The AHP method was used to determine weights of the criteria and the TOPSIS method was used to obtain the final access network ranking. Grey relational analysis combined with fixed user's preferences to choose optimal network was devised in [138]. The proposed approach has decreased packet blocking probability and packet loss rate, as well as improve user satisfaction. MADM techniques suffer from ranking abnormalities. The ranking abnormality happens when the low ranking alternative is removed from the candidate list the ranking order of the alternatives changes. This difficulty was addressed by adopting hybrid multi attribute decision making methods in [134]. A classification method was initially applied to gather the criteria in a whole of the homogeneous classes. Afterwards AHP was applied to determine weight of inter classes and intra-classes. TOPSIS was used to rank the alternatives.

Network Assisted Network Selection (NANS) was introduced as service based, network based and user based criteria for network selection in [149] and used Generalized Assignment Problem (GAP) and AHP to assign the network resources to a set of users. The mechanism combined AHP and WPM to select an appropriate access network for each user application in [150]. It made possible the full usage of network resources while reducing energy consumption and monetary costs.

• ***VIKOR***: VIKOR [115,117, 151-153] is an MADM method that is developed to optimize the multi attribute based complex systems. It is a compromise programming approach that is based on an aggregating function that represents closeness to the ideal solution. Thus, VIKOR is able to determine a compromise ranking list of alternatives in the presence of conflicting criteria. A comparative analysis of some of these methods with numerical examples, for voice and data applications, in a 4G wireless system was proposed in [114]. It was shown that methods such as SAW, TOPSIS, and VIKOR were suitable for voice connections, whereas GRA and MEW provided a better performance for data connections. Another comparison of these methods, using bandwidth, delay, jitter, and BER as system's parameters was shown in [115]. Results showed that MEW, SAW, and TOPSIS provided similar performance to the four different classes of traffic (Conversational, Interactive, Streaming and Background) that were used. GRA provided a slightly higher bandwidth and lower delay for Interactive and Background traffic classes. Results also demonstrated that the performance of these algorithms dependent on the priority weights assigned to the system parameters. Two modules were designed to estimate the necessity of handoff and to select the target network in [154]. These modules utilized parallel Fuzzy Logic Controllers (FLCs) with reduced rule set in combination with a network ranking algorithm developed based on Fuzzy VIKOR (FVIKOR) Simulation results were provided and compared with a benchmark.

2.3.9. Mathematical theories based algorithms: The wide number of factors (e.g., single or multi-technology, single or multiple operators, centralized or decentralized solution, different number of parameters, different types of utility functions, type of game, etc.) considered by different approaches, it is very difficult to compare them in terms of computational complexity. Thus, further investigation is required to evaluate the impact of the computational complexity for mathematical theoretic based network selection solutions.

Authors in [155], modeled access selection as a binpacking problem and realized that the problem was NP complete. Therefore, a heuristic algorithm called Less Damage was developed that calculated a damage parameter and used it as a metric for the allocation strategy. Less Damage performed better in terms of blocking probability and elastic data throughput than available online binpacking heuristics, in competition of the number of the available access technologies. Effective network selection strategies were proposed and analyzed by taking into account location dependent user mobility, multi service traffic characteristics and heterogeneous QoS support. A service differentiated network selection strategy was studied for conversational voice service and interactive data service in [156]. Then, the heavy tailedness of data traffic was further exploited with a size based network selection strategy. Also, network reselection via dynamic vertical handoff was considered for interworking enhancement. Effective analytical approaches were developed to evaluate system performance. Important insights were gained about the impact of user mobility and multi service traffic characteristics on network selection. A dynamic access network selection algorithm capable of adapting to prevailing network conditions was proposed in [157]. It was a dual stage estimation process where network selection performed using sequential Bayesian estimation relies on dynamic QoS parameters estimated through bootstrap approximation. It outperformed the static optimization approach in a highly efficient manner. In [158], two oligopolistic models for price competition among service providers in a heterogeneous wireless environment was proposed consisting of WiMAX and Wi-Fi access networks. A non-cooperative game was formulated to obtain the price for the service providers. The Nash and Stackelberg equilibrium were considered as the solutions of the simultaneous play and leader follower price competitions respectively.

The dynamics of network selection in a heterogeneous wireless network using the theory of evolutionary games was studied in [159]. The competition among groups of users in different service areas to share the limited amount of bandwidth in the available wireless access networks was formulated as a dynamic evolutionary game, and the evolutionary equilibrium was considered to be the solution to the game. Population evolution and reinforcement learning algorithms were presented for network selection. The network selection algorithm based on population evolution required a centralized controller to collect, process and broadcast information about the users in the corresponding service region. On the contrary, with reinforcement learning, a user gradually learned (by interacting with the service provider) and adapted the decision on network selection to reach evolutionary equilibrium without any interaction with other users. Dynamic evolutionary game based network selection algorithms were empirically investigated. [160] presented a discussion on the application of game theory to the network selection problem faced by the next generation of 4G wireless networks and also gave a comprehensive classification of related game theoretic approaches.

A best permutation scheme (Basic Besper) for mobility based network selection in a generic HWN environment in [161] and two methods (i.e. Simplified Besper and Enhanced Besper) to further improve the time complexity of Basic Besper. According to performance evaluations, Bespers could always select the best network and permutation based on mobility related factors and many advantages compared with classic best network schemes were demonstrated. Furthermore, the two methods (especially Enhanced Besper) could find the best network quite rapidly, which was important for the continuity of real time applications during vertical handoffs.

In heterogeneous wireless networks, rank aggregation based on multiple decision factors [162] was proposed as a useful approach for network selection in [163]. For each decision factor, a rank of the candidate networks was derived according to the value of the decision factor. Then these decision factor dependent ranks were aggregated into a single rank and the top one was considered as a favorite network. However in the realistic scenario, the measurement on decision factor was often inaccurate so that the candidate networks were possibly not ranked appropriately. As a result, if there exists the slight differences between the decision factor values of several candidate networks, same rank was preferable to these networks. The set of networks was therefore separated into several groups and these groups were ranked accordingly. Moreover the networks tied in the same group had the same rank. A new approach namely 'median based network selection method' was, therefore, proposed to handle such partial tied rank aggregation problem. Authors in [164], introduced the concept of mathematical mechanism for network selection based on strategy space and quality points in the game theoretical framework. It was conceptually shown that only the best network served the service request of the user but not implemented practically. Global Arbitration Process (GAP), a scheduling approach to dynamic network selection that combined application-oriented and device wide decision constraints was presented in [165]. In contrast to existing approaches, GAP didn't only decide on single networks, but allowed to assign network bundles to applications or to proactively delay data transmissions.

A measurement based network selection technique that estimated QoS information by bootstrap approximation and filtered unnecessary handovers by Bayesian estimation in conjunction with cumulative sum (CUSUM) monitoring was proposed in [166]. This technique effectively augmented the handover decision of existing cost function approach, which only selected the most suitable network by including the ability to decide whether handover was necessary for optimal network selection in presence of dynamic QoS parameters. There is a lack of numerical analysis of the radio access technology selection algorithms performances, since most of the analyses found in the literature is based on computer simulations. A Radio Access Technology (RAT) selection in heterogeneous wireless networks based on service type, user mobility and network load was presented in [167]. Performances of the algorithm were evaluated by using Two-dimensional Markov chain and compared in regard to different single and two criteria RAT selection algorithms and showed overall better performance. In [168], network selection problem was formulated as an unsupervised learning problem. A decision tree based approach was then proposed to fully utilize the decision factors with different types to select network optimally. Actually there were lots of decision factors which were very useful for network selection. The values of these decision factors belong to different types such as discrete, boolean, enumeration, and continuous values, it was quite difficult to make use of these decision factors in traditional network selection approach.

In [169], the Dempster-Shafer Theory (DST) was applied to more complicated scenarios during network selection. The basic idea was to combine the network evaluations (i.e. degrees of belief) judged from the viewpoints of different constraint factors to arrive at an agreement with joint mass for each network. Thus a rank of these networks was obtained and the one with the largest joint mass in the rank selected as the best network. The dynamic network selection paradigm that used user profiling to rank networks for selection and ignore networks with less capacity than required , using the Knapsack problem 0/1 dynamic algorithm and the Knapsack problem optimization algorithm was proposed in [170].

2.3.10. Fuzzy logic based algorithms: Just like the cost function and MADM based approaches, this category of algorithms also takes advantage of combining multiple parameters. In addition, the Artificial Intelligence (AI) based schemes such as fuzzy logic, neural networks, expert systems, and Genetic Algorithms (GA) are used to perform network selections. As discussed previously, classical techniques, which are based on evaluation of imprecise metrics, fail to perform efficient network selection decisions. Fuzzy logic based schemes can be used to perform efficient selections as these can effectively deal with known sensitivities of network parameters with the help of inference rules that are based on expert human knowledge. On the other hand, handoff data can be used to train neural networks to perform these decisions in an efficient manner. Fuzzy logic, combined with Artificial Neural Network (ANN) or GA, can be used to develop adaptive approaches to make highly optimized network selections.

In [171], handover decision was identified as a fuzzy Multiple Attribute Decision Making (MADM) problem and fuzzy logic was applied to deal with the imprecise information of some criteria and user preference. For handover decision, imprecise data was first converted to crisp numbers, and then, classical MADM methods SAW and TOPSIS were applied. Numerical results showed that TOPSIS was more sensitive to user preference and attribute values, and SAW gave a relative conservative ranking result. Authors in [172], presented a mobile terminal architecture for devices operating in heterogeneous environments. It incorporated intelligence of mobility and roaming across legacy access networks. It focused on the structure and functionality of the proposed scheme that supports terminal initiated and terminal controlled access network selection in heterogeneous networks. It independently determined the optimal local interface and attachment point while taking into account network status and user preferences, resource availability and service requirements. Combined fuzzy logic and GAs had been used to solve the multi criteria Access Network Selection (ANS) problem in [173]. The proposed scheme used to present and design general multi criteria Software Assistant (SA) that can consider the user, operator, and/or the QoS view points and provided required scalability, flexibility, and simplicity Results showed that the proposed scheme and SA had better and more robust performance over the random-based selection. The fuzzy neural methodology framework in [174] was able to take into consideration different operator policies as well as different subjective criteria by means of a multiple decision making mechanism, such as giving more priority to the selection of one RAT in front of another one or balancing the traffic among the RATs.

A user centric network selection approach using multi attributes auctioning mechanism was carried out in [175] while considering negotiation between network operators and users. The utility of users and the network operator's utility considered and discussed the truth telling behavior of network operators in terms of offered prices and service quality. Fuzzy logic approach was used to the reduce frequency of handovers. An Autonomic Interface Selection Architecture (AISA) based on fuzzy control was proposed in [176] to select a servicing interface dynamically and automatically. The AISA selected a suitable interface among several accessible interfaces, for each application based on diverse autonomic decision policies. This architecture sensed and interpreted contextual changes in the network, and adapted to meet changing network environment and user requirements in selecting an interface. AISA utilized human experience in terms of fuzzy set to select the most favorable interface for an application in an autonomic way.

A User Preference oriented Network Selection algorithm (UPNS) was proposed by combining entropy theory and Fuzzy Analytic Hierarchy Process algorithm (FAHP) in [177]. A Service Level Agreement (SLA) management model was designed for network selection control in heterogeneous wireless environment and a management model instance based on UPNS. Implementation of the UPNS algorithm results in improved efficiency in satisfying user's individuality and maintaining user satisfaction. A neuro fuzzy multi parameter based Vertical Handoff Decision Algorithm (VHDA) was proposed in [178]. It considered six parameters and applied rule based system for vertical handoff decision. The amount of vertical handoffs calculated in a simulated environment showed that average number of vertical handoffs for the proposed VHDA reduced by 13.3% and 29.8% for the existing fuzzy technique and the classical technique, respectively. Auxiliary, diminution in number of unnecessary vertical handoffs in the proposed algorithm showed reduction in ping pong effect by 15.9%, improvement in End point Service Availability (ESA) and throughput by 16.57% and 5.97%, with respect to existing fuzzy technique leading towards better QoS. Finally, the results of performance assessment, conceded using handoff quality indicator (used to quantify QoS) which dependent upon ping pong effect, ESA and throughput, showed that the proposed VHDA offered better QoS than existing vertical handoff techniques.

The proposed algorithm in [179] used genetic algorithms, fuzzy logic controllers and particle swarm optimization for decision making under given input criteria on type of service, service parameters, user velocity and quality of service, service costs for the mobile user. A network selection algorithm based on fuzzy multiple attribute decision making was dealt in [180]. The algorithm considered the factors of Received Signal Strength (RSS), Monetary cost(C), Bandwidth (BW), Velocity (V) and user preference (P). It was observed that the Network Selection Function (NSF) measured the efficiency in utilizing radio resources by handing off to a particular network. The network that provided highest NSF was selected as the best network to hand off from the current access network.

Radio Network Selection (RNS) solution was developed by combined use of parallel fuzzy logic control and MCDM system to achieve more scalable, flexible, general, and adaptable solution. The solution in [181] has better and more robust performance over several reference algorithms. A multi-criteria algorithm User Specific Intelligent Vertical Handoff (UIVH) for heterogeneous wireless network which used Adaptive Neuro Fuzzy Inference System (ANFIS) to select the best network for VHO was presented in [182]. UIVH is based on Sugeno Fuzzy Inference System (FIS) to decide when to perform handoff. ANFIS was used to rank different wireless networks for VHO based on set of parameters along with user preferences on a mobile device. UIVH was intelligent and adaptive and balanced overall load of HWN. UIVH always selected best available network to accommodate the specific requirements of users. Gradual increase in handoff completion time was observed with gradual increase in number of handoffs. A QoS aware fuzzy rule based vertical handoff mechanism that made multi criteria based decision was found to be effective for meeting the requirements of different applications in a heterogeneous networking environment in [183]. The QoS parameters considered were available bandwidth, jitter, end to end delay and bit error rate. An evaluation model was proposed using a non birth death Markov chain. The states correspond to the available networks in it. The proposed algorithm gave better performance for different traffic classes as compared to other vertical handoff algorithms.

2.3.11. Optimization techniques based algorithms: The network selection criteria are required to meet the optimization objectives of the decision maker to support seamless mobility and optimal network access in next generation heterogeneous network. A network selection algorithm was proposed for optimal service delivery over consumer devices capable of heterogeneous access networks, when the user had a choice between multiple service delivery networks in [184]. The different networks were chosen for all different services with service requirements and user demands. To make a choice for network selection on given time intervals, past knowledge of the service performances of available wireless networks was used by the mobile. Particle Swarm Optimization (PSO) was implemented for optimization of fuzzy logic controllers and genetic algorithm outputs to make decision on multi-criteria inputs. The proposed algorithm gave better probability of satisfied users compared to other existing wireless network selection algorithms [185]. A Policy based Radio Access Selection and Optimization (PRASO) algorithm was proposed in [186].

PRASO algorithm was the combination of two policies named Overall User Satisfaction Improvement (OUSI) policy and User Number Increase (UNI) policy. This algorithm facilitated radio access network selection and optimization while considering application requirements, user satisfaction, network resource availability, gains and utilization. The proposed algorithm improved the network performance in term of capacity.

An optimal distributed network selection scheme in heterogeneous wireless networks considering multimedia application layer QoS was proposed in [187]. Specifically, the integrated network as a restless bandit system was formulated. With this stochastic optimization formulation, the optimal network selection policy was indexable, meaning that the network with the lowest index selected. The proposed scheme was applicable to both tight coupling and loose coupling scenarios in the integration of heterogeneous wireless networks. A PSO Fuzzy Neural Network (FNN) based vertical handoff decision algorithm was proposed in [188] with the aim to work out the problem load state that fuzzy logic and neural network based vertical handoff algorithm didn't consider in heterogeneous wireless networks. The algorithm executed factors for the FNN with the objective of the equal blocking probability to adapt for load state dynamically, and combined with PSO algorithm with global optimization capability to set initial parameters in order to improve the precision of parameter learning. The PSO FNN algorithm balanced the load of heterogeneous wireless networks effectively and decreased the blocking probability as well as handoff call blocking probability compared to Sum Received Signal Strength (SRSS) algorithm. To facilitate better network selection a load distribution model was also introduced in [189]. Researchers focused on the optimization of network resource utilization using the PSO with the objective to distribute the system load according to the various conditions of the heterogeneous networks in order to achieve minimum system cost. The proposed approach outperformed the conventional iterative algorithm by a cost improvement of 7.24% for network size of 1000 mobile terminals using 10 particles. An optimal handover solution of assigning N terminals to M access networks was found based on multi PSO with optimum mutation in [190]. Pareto optimum under Nash equilibrium of both user utility and network provider utility was achieved or approached for the initial solution with the help of gaming analysis.

A hybrid modified PSO algorithm to select the best access network among Wireless Wide Area Network (WWAN) and WLAN was proposed in [191]. A variant of PSO called modified PSO was used in which a constriction coefficient introduced in the velocity update equation and this factor improved the convergence of the particle over time and this optimization algorithm hybridized with multi-objective decision making algorithm and weighing function to achieve better solutions. It was found that the proposed approach gave higher user satisfaction ratio compared with the other approaches. Vertical Handoff Decision Making Algorithm (VHDMA) based on analytic multi objective optimization proposed was in [192]. The multi objective cost function involved transmits power of Mobile Terminals (MTs), outage and throughput over APs/ BSs. The proposed algorithm lowered the barriers and jointly optimized all the required objectives. The Multi Objective (MO) optimization had the advantages of optimizing over different and conflicting objectives jointly. Authors in [193] introduced a mixed integer linear optimization problem to optimize handovers while considered the costs of handovers (such as signaling and communication interruption). Optimization scheme used estimates of future station arrivals and mobility patterns and robust against estimation errors. Authors in [194] supplied a concise explanation of various models, principles, algorithms, tools, and optimization techniques such as artificial neural networks, fuzzy systems, evolutionary algorithms, and hybrid algorithms.

2.3.12. Hybrid algorithms: A single network selection criterion is unable to provide required QoS and GoS while selecting a network in heterogeneous environment. It is required to hybrid network selection techniques to achieve simple, general, scalable, flexible, and adaptable solution. Network selection based on available bit rate and timing constraint for multimedia capable cellular system was proposed in [195]. Handover must be initiated at different positions for different services to maintain the required quality of service requirements. Fuzzy logic control and MCDM system were combined in [196]. The first layer of the algorithm used small fuzzy logic based subsystems, where each subsystem represented one input criteria. The fuzzy logic was used to overcome the complexity and fuzziness associated with the heterogeneous wireless environments and their services and to make the proposed algorithm simpler and more adaptable. In the second layer, the algorithm used a MCDM technique that taken the first layer output as its input. The MCDM ensured that all of the different characteristics and viewpoints were taken into account when making the radio access network selection. An adaptive multi criteria vertical handover framework was presented in [197]. The framework set the handover threshold according to the ongoing service in order to guarantee the basic connection quality requirement of the ongoing service. When the handover was triggered, this framework selected the best access network in an effective order determined by the basic characteristics of the service using the fuzzy logic. AHP was typically used to calculate the integrated value of multiple criteria and made the handover decision in which the human aspect was involved to determine the importance between different criteria. After the handover was processed, the QoS reconfiguration was used to adapt the ongoing service to the new network if necessary. An architecture that combined QoS Broker and network Selection was proposed in [198]. The QoS Broker monitored the QoS performance in all the time for each wireless network for each traffic class. The user demand for precise service generally depends on available bandwidth and the service QoS parameters; if any network with sufficient traffic bandwidth and QoS parameters, that matched the user request, then the connection to that network is triggered and established with optimum selection for both end-user and network operator.

Although many works can be found on heterogeneous wireless networks, most of them focused on protocol design and/or theoretical performance study. Very few of existing works reported real system development, of which most were limited to integration of WLANs and cellular networks. In [199], Heterogeneous Advanced Wireless Network (HAWK), a real-world implementation of high performance heterogeneous wireless networks for ubiquitous Internet access was presented. A fully featured test bed comprising of different wireless networks, including Wireless Mesh Network (WMN), WLAN and 3G network and dual mode mobile clients that could access any of these networks has been designed. The design aspects include both hardware and software implementation thus making the proposed design suitable for practical deployment.

A comprehensive survey of the basic elements and the different types and phases of the horizontal handoff procedure was provided in [200]. A comprehensive survey of the vertical handoff algorithms was presented in [201] to provide the required QoS to a wide range of applications while allowing seamless roaming among a multitude of access network technologies. To offer a systematic comparison, the algorithms were categorized into groups based on the main handover decision criterion used and evaluated the tradeoffs between their complexity of implementation and efficiency.

A platform for access selection algorithms in heterogeneous wireless networks, called ABCDecision was presented in [202]. The simulator implemented the different parts of an ABC system, including Access Technology Selector (ATS), Radio Access Networks (RANs), and users. The proposed algorithm achieved a load balancing distribution between networks by taking into consideration the capacities of the available cells in terms of the occupancy rate. A vertical handoff decision algorithm for non real time and real time services and network selection for WLAN/WiMAX/UMTS were presented in [203]. The condition of handoff decision procedure considered predictive RSS of the target networks, RSS of current serving network and residence time in the target network if their conditions were consistently true during dwell time to reduce connection dropping and unnecessary handoffs. Back propagation neural network was used for RSS prediction. The handoff policy while mobile was located in WLAN/WiMAX and UMTS were different to prolong staying in WLAN/WiMAX due to its high bandwidth, low cost and to reduce handoff delay for existent time services in WLAN/WiMAX. The merit function was used as a handoff metric for evaluating network performance based on user preference in order to decide candidate networks for client. Network selection strategy based on fuzzy logic using quantitative decision algorithm to determine which access network should be chosen for handoff criteria. The proposed handoff scheme chooses the optimum network through considering between the user preference and network conditions and outperformed the other approaches in terms of handoff call dropping probability, number of handoffs and GoS.

Another multi level rule based vertical handover approach was proposed in [204]. In this approach the decision rules were obtained by means of data training. Different sets of decision rules were derived for different applications. These rules expressed relationships between parameters. Furthermore, the decision rules could be modified, if needed. The modifications included adding new rules, updating the existing rules to reflect the changing environment and removing or ignoring unwanted rules in order to minimize computation time. The proposed rule based approach simulated while considering a number of decision parameters, for various applications. The rule based approach offered superior network selection in terms of data rate and usage cost. For other decision parameters, it offered a network selection that was comparable to MADM based techniques. Unlike the traditional handover algorithms which selected the best network, the investigated solution estimated the capacity of each network and dynamically distributed the application traffic over the available networks accordingly by using quality of multimedia streaming. It is a comprehensive and flexible metric for estimating the amount of traffic each network can hold. Performance evaluation of the proposed algorithm was done in term of user quality of experience in [205].

In [206], authors combined two Multi Attribute Decision Making (MADM) methods - Analytic Network Process (ANP) method to weigh the multi criteria function and the novel method depends on Mahalanobis distance (NMMD) to rank the alternatives. It eliminated the packet jitter and packet loss while network selection by deducing correlation between packet delay, packet jitter and packet loss. Another multi criteria vertical handoff algorithm, which chose the target Network Access Technology (NAT) based on several factors such as system parameters, user preferences and traffic types with varying QoS requirements was presented in [207]. Two modules i.e., VHO Necessity Estimation (VHONE) module and target NAT selection module, were designed. Both modules utilized several ‘weighted’ user’s and system’s parameters. To improve the robustness of the algorithm, the weighting system was designed based on the concept of fuzzy linguistic variables.

Two more proposals were presented in [208] in order to solve the problem of network selection. One combined the fuzzy method with two MADM methods, the AHP and the GRA, whereas the second used the fuzzy logic technique only. Then two were compared with each other and with a third proposal, which used a combination of AHP method along with a cost function. The results showed that the first two proposals were more efficient to sort and select the best access network as compared to the third one.

An integrated scheme using multiple attribute decision making as the core of the network selection procedure was proposed in [209]. An integrated scheme combining the advantages of several mathematical theories was proposed in literature. To solve the problem of choosing the best access network available in the environment where the user is located, a combination of fuzzy logic technique with two decision making methods, AHP and GRA, was proposed in [210]. It was observed that the decision making methods were useful in sorting alternatives in order to achieve a goal, and together with an artificial intelligence technique, the result became even more accurate. In order to provide ubiquitous access for the users, a ranking algorithm was proposed in [211]. It combined MADM and Mahalanobis distance. A classification method was applied to build classes having homogeneous criteria. Afterwards, the Fuzzy AHP, MADM methods were applied to determine weights of inter-classes and intra-classes. Finally, Mahalanobis distance was used to rank the alternatives. It effectively reduced the ranking abnormality and the number of network selections. In [212], authors used AHP to take interview responses from wireless network providers as input and generated weight assignments for each attribute for network selection and resource allocation. The attributes considered by the multi-attribute optimization function consisted of system spectral efficiency, battery lifetime of each user (or overall energy usage) and long term fairness for each user in the system.

An analytical model was proposed in [213] to capture the preferences of end users. Based on this model, an Automatic Network Selection (ANS) mechanism designed to take into account all aspects of the tradeoff between the preferences of the end users, the quality of the connections, and the cost. The proposed function can be used as an acceptance probability for the network operators' radio resource management. The suitability and the effectiveness of the proposed functions have been analyzed using numerical analysis and using a new multi technology network simulation platform. An important highlighted result was that the network access selection eventually not only benefited the end users but increased the revenues of network operators as well. This result can help the wide deployment of ANS in future Mobile Terminals (MTs) and smart phones. The proposed solution is preferred choice over mainstream approaches.

2.3.13. Brief comparison of the approaches: This section provides a comparison of the different network selection approaches that have been discussed in the above sections. Since the decision phase is the most important one in the network performance, end user preferences and satisfactions, efficiency, flexibility, and complexity and reliability of the overall algorithm, so it must be considered when evaluating and comparing these network selection approaches. Based on the discussions in Sections 2.3.1-2.3.12, different combinations of these criteria can be used to perform network selection decisions: Bandwidth, SIR, network usage cost, user's preferences, QoS preferences, MS's available battery power, delay, throughput, jitter, response time, BER, burst error, packet retransmissions, packet losses, security preferences, network coverage area, RSS, Traffic load, type of provided services, number of active MSs, and speed of MS's. In most of the cases, a decision strategy involves complex considerations and many tradeoffs must be made to provide an efficient decision mechanism while keeping the overall complexity at the minimum. In terms of complexity, single criterion based handoff algorithms (especially RSS based) are usually the simplest among all the categories. On the other hand, multi criteria based handoff algorithms not only require the collection of several network parameters but these parameters must be normalized as well. Hence these are more complex than the RSS based or bandwidth based handoff techniques. AI based handoff techniques are more challenging and complex due to their pre training and other requirements. In terms of reliability, AI based handoff algorithms are considered to be the most reliable among all the others, as these systems are trained beforehand. These algorithms are well-suited for decision problem as these can provide accurate solutions by taking into account multiple decision factors. With respect to overall processing delays, AI based approaches suffer from the highest delay due to increased system complexity. On the other hand, processing delay might be relatively lower in other techniques; nevertheless, these techniques have significantly high handoff failure probabilities, high number of handoffs, and high number of unnecessary handoffs, which reduces the overall system performance.

2.4. Research gaps

Network selection mechanism is dependent on the reachable networks, the subscriber's user profiles and the applied services. In [5] authors have presented the network selection algorithm based on the AHP and GRA mathematical methods. The network selection mechanism is tracking the users' priorities and the various demands of the different services. In their future work they proposed to design a service oriented network architecture based on their network selection method. In this case no fixed service providers shall be assigned to the subscribers they can select from wide range of services from a trusted third party anytime and anywhere. These services can be accessed via one of the available networks.

Authors proposed a dynamic and user centric network selection method mechanism that is effective in providing an Always Best Satisfying (ABS) network to the end-user based on user policies and relevant network parameters. However, providing an ABS at any instance in time may result in high frequency of handovers which may degrade the network performance. They therefore proposed some algorithms to reduce such frequency and provide a simple evaluation. Such results showed that the algorithms were successful in balancing the user requirements with the frequency of handovers, thus resulting in a better network selection process. The performance of each algorithm is needed to be studied further within an analytical model in future work [52].

The decision about network selection in a heterogeneous wireless environment is dependent on several factors. The network selection problem can be solved using MADM algorithms. They can be used in combination with fuzzy logic where input attributes values are not clearly defined. Among the most widely discussed MADM mechanisms are ELECTRE [214], TOPSIS [215], AHP [216-217], GRA [7], Weighed Sum Model (WSM) [215], and WPM [209]. The mechanism described also utilized an MADM [216] approach for network selection, but with only a limited number of parameters and without an architectural framework. Factors such as the roaming agreements of the user's home network, the authentication methods, and the type of mobility of the user were not taken into consideration. Scenarios where the access network could support multiple levels of QoS or the user was already using a network for an earlier session were not addressed. Moreover, issues of sensitivity of the selection process to input data were not explored [141].

The mechanisms described above have a few weaknesses. The factors considered in the decision process are insufficient; for example, information about access types supported, authentication types supported, and roaming partners supported are not considered in the decision process described in these methods. They also did not provide or refer to a viable architectural framework in which the selection mechanism can work. The user case scenarios described were limited and not realistic from the perspective of deployment or the business models used in the industry. As a result, they [141] did not provide complete and deployable solutions to the problem.

Selection of an optimal access network is an important aspect of service delivery in a heterogeneous wireless system. Scenarios with different services and subscribed QoS profiles have been observed. Possible approaches to network selection when a service is already in use have been discussed, and solutions are proposed. The results of this have provided a basis for further research into the area of different service delivery in a heterogeneous network environment [52].

Proposals are also there to combine the end to end QoS architecture for NGN scenarios applied with a multilink architecture to support central dynamic network selection [218]. It is clear that this combination will result in sustaining dynamic network selection with the QoS meeting the user requirements, dynamically and in roaming environments. When the end user requests a service, the request will be forwarded to the QoS Broker in the core network. The QoS broker will determine the best available network resources for the requested service, the decision of the best network will be then forwarded to a multi-link gateway (in the core network). The ML (Master Link) gateway acting as a main gateway to other gateways connected to the backbone network to allow the convergence of multi-access network. At the end the ML gateway will route the IP packets, to the gateway which will attach the end user with the most suitable network.

Researchers described a distributed management approach for providing end to end quality of service over heterogeneous networks. This system covers an entire audio–visual service distribution chain, including protection and content generation, distribution across QoS enabled heterogeneous networks and delivery of content at user terminals. The whole content delivery chain was considered, including content, network, and service providers. They focused their attention on service provisioning, multimedia content management, and QoS provisioning over heterogeneous networks. They developed a customer/end-user service framework, defining and offering services through service providers. Service provisioning and service offering are achieved in a scalable manner. In providing a QoS enabled inter domain networking infrastructure, a QoS based signaling protocol suite is proposed for service subscription, resource allocation and monitoring purposes. The dialog between different stakeholders in the content delivery chain is considered as an important factor and a protocol is developed for these negotiations. Service and resource monitoring is essential for service providers. Means are developed to exchange measured information and monitor the services, networks, and resources. They believed that the presented approach is scalable and can support the QoS based service offering to a large number of customers across heterogeneous environments. Finally, they have completed the design stage in which the proposed functional blocks of the architecture have been specified in terms of interfaces to other blocks, behavior and algorithms. Researchers [219] are currently at the stage of implementation and validation. They would experiment the system through both testbed environments and simulators in order to be able to deal which are stress conditions, large scale networks etc.

Besides the aforementioned decision mechanisms, authors also discussed QoS and mobility that come with the arrival of multimedia in wireless networks. These two issues influence the research and development in wide areas, and they needed to be considered each time new scheme. Besides, there has been an ongoing debate on architectural design in terms of system performance and finally, hybrid scheme is recommended for good performance of the system because it controls globally while still being scalable performance evaluation of existing schemes usually based on network load (access networks and total load), connection blocking, processing capacity requirement, connection dropping, throughput, delay, bandwidth utilization, and number of handovers. However these [143] did not give a common evaluation because each scheme has a specific goal and consequently these used different metrics for the evaluation.

Multimedia applications must adjust their QoS according to the heterogeneous terminals with variable QoS requirements and support. To ensure that multimedia applications will be supported with guaranteed QoS, it is not enough to merely assign resources. It is essential that distributed multimedia applications guarantee end to end QoS of media streams, taking into consideration both the end terminals and the networks. The deprivation in the constricted QoS is often inevitable, thus there is a need to create available real time QoS monitoring that not only is proficient of monitoring the QoS support in the network but that can also take actions in real time manner to maintain an acceptable multimedia quality when the QoS level degrades. At present, there is variety of networks; wired and wireless. These are coexisting and have QoS characteristics that are significantly dissimilar and whose degree of inconsistency of the diverse QoS parameters, such as bandwidth, jitter and delay. Moreover, there are diverse kind of terminals, such as personal digital assistants (PDA), desktop computers, laptop computers, and cell phones, each with some multimedia support. Therefore, multimedia applications must adjust their QoS according to the heterogeneous terminals with variable QoS requirements and support.

Multimedia applications over heterogeneous wireless environments have also drawn the attention of the research area. The summary work gives a complete appearance of potential streaming systems in wireless networks and discusses the standardization efforts. The authors evaluated different mechanisms for robust streaming over wireless networks. They proposed an adaptive cross layer protection strategy for robust and efficient scalable video streaming, by performing tradeoffs between throughput, reliability and delay, depending on the channel conditions and application requirements. On the other hand there are efficient techniques for streaming over wireless networks which offer some QoS guarantees. Additionally, the authors presented a resource allocation framework based on service differentiation and analyze the capacity benefit achieved through service prioritization and dynamic rate adaptation. Most of these works address the problem of media streaming alone, and do not consider the larger setup, when different applications, with possibly different quality requirements share the same wireless medium. At the same time, they do not address systems where multiple wireless services can be inter worked in order to improve the end user experience.

Service inter working is slowly emerging as a viable commercial solution in order to achieve a better end user application quality, over unreliable wireless transmission mediums. While initial commercial products already exist, standardization efforts are paving the way towards more advanced products and services. The authors present handover possibilities between WLAN and cellular wireless systems and discuss the possible issues and problems [216].

However, the above works do not address the problem of resource allocation and network selection when multiple users have access to several heterogeneous networks, administered by the same operator.

2.5. Summary

In this chapter, a comprehensive literature survey has been presented on network selection. Major problems in the existing algorithms for network selection have been identified. It is observed that there are still some open issues which need further investigations. Some important open issues are: minimization of the computational complexity of the existing solutions, reduction in probability of unnecessary network selection, probability of network selection failure and overheads, maximization of utility factor, seamless mobility provision, and ubiquitous communication.

CHAPTER 3

NETWORK SELECTION BASED ON QoS PARAMETERS IN HETEROGENEOUS WIRELESS NETWORKS

3.1. Introduction

Network selection in a heterogeneous wireless environment is a major challenge to ensure seamless mobility across different radio air interfaces. In order to provide required QoS for a given application in multimedia environment, different parameters including packet delay, packet loss, bandwidth and cost per byte play important roles in network selection. We consider a heterogeneous environment comprising of UMTS, WLAN, GPRS, and WiMAX. Further, TOPSIS- a MADM algorithm based on AHP used as multi criteria decision method is employed for network selection. Then we propose a network selection algorithm in which weight estimation for the representative set of the network attributes is computed using entropy and TOPSIS approach. The proposed model was implemented to select the desired network in a heterogeneous environment employing triple play services. The model selects the desired network in heterogeneous environment in accordance with the required QoS for the application under consideration. A novel method that takes into account user preferences, network conditions and QoS in order to select the optimal network which achieves the best balance between user and network performance is proposed. It incorporates the use of parameterized network and user profiles in order to model diverse QoS flexibility for different real time and non-real time applications.

3.2. Quality of Service based network selection in heterogeneous wireless networks

A well-known set of methods for decision making is MCDM or MADM based on the AHP technique is a general class of models which deal with decision problems in the presence of a number of decision criteria. The final decision is highly dependent on the preferences of the decision maker and must be a trade-off. MADM techniques are based on a deterministic approach and have been used widely in operations research for decision making where the results are known to be affected by several factors. Several MADM algorithms including TOPSIS, GREY, and ELECTRE have been described in [214, 216-219]. TOPSIS a compensatory MADM algorithm has been applied to the problem of network selection. It shows that for the given problem, ranking of only the top candidate is important.

TOPSIS is a widely used MADM algorithm developed by Yoon and Hwang [215]. It is applicable for problem spaces that have the attributes with monotonically increasing or decreasing levels of utility. The algorithm calculates perceived positive and negative ideal solutions based on the range of attribute values available for the alternatives. The idea of the algorithm is that the best solution is the one with the shortest distance to the positive ideal solution and longest distance from the negative ideal solution. Distances are measured in Euclidean terms. All solutions with the same preference level can be mapped to an indifference curve. The indifference curve shows how different values of attributes when combined can result in the same level of preference. For the network selection problem, the set of attributes cost per byte (CB), total bandwidth (TB), available bandwidth (AB), utilization (U), delay (D), jitter (J) and packet loss (L) are considered [7] in the decision making process using TOPSIS. Using these attributes, a candidate's network (NW) selection using MADM can be represented as:

$$NW = [CB\ TB\ AB\ U\ D\ J\ L] \tag{3.1}$$

If there are N network alternatives to be considered in the selection process, these can be represented in the form of a matrix as follows,

$$NW_i = \begin{pmatrix} CB_1 & TB_1 & AB_1 & U_1 & D_1 & J_1 & L_1 \\ CB_2 & TB_2 & AB_2 & U_2 & D_2 & J_2 & L_2 \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ CB_N & TB_N & AB_N & U_N & D_N & J_N & L_N \end{pmatrix} \tag{3.2}$$

The TOPSIS algorithm has been applied as follows. [7]

Step 1. The value for each of the attribute in the matrix is normalized. Entries in the first column of the matrix can be normalized as:

$$(CB_{norm})i = \frac{CB_i}{\sqrt{\sum_{i=1}^{N} CB_i^2}} \tag{3.3}$$

Step 2. The matrix is updated with these normalized values as:

$$(NW_{norm})_i = \begin{pmatrix} (CB_{norm})_1 & (TB_{norm})_1 & (AB_{norm})_1 & (U_{norm})_1 & (D_{norm})_1 & (J_{norm})_1 & (L_{norm})_1 \\ (CB_{norm})_2 & (TB_{norm})_2 & (AB_{norm})_2 & (U_{norm})_2 & (D_{norm})_2 & (J_{norm})_2 & (L_{norm})_2 \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ (CB_{norm})_N & (TB_{norm})_N & (AB_{norm})_N & (U_{norm})_N & (D_{norm})_N & (J_{norm})_N & (L_{norm})_N \end{pmatrix} \tag{3.4}$$

Step 3. The next step is to decide on the relative importance of each of the attributes involved in the decision about network choice. For this intention, each of the attribute is assigned a weight '*w*', such that

$$W = W_{CB} + W_{TB} + W_{AB} + W_U + W_D + W_J + W_L = 1 \tag{3.5}$$

Step 4. Using these assigned weights, the matrix from step 1 is updated as follows.

$$NW_{norm} = \begin{pmatrix} W_{CB}*(CB_{norm})_1 & W_B*(TB_{norm})_1 & W_{AB}*(AB_{norm})_1 & W_U*(U_{norm})_1 & W_D*(D_{norm})_1 & W_J*(J_{norm})_1 & W_L*(L_{norm})_1 \\ W_{CB}*(CB_{norm})_2 & W_B*(TB_{norm})_2 & W_{AB}*(AB_{norm})_2 & W_U*(U_{norm})_2 & W_D*(D_{norm})_2 & W_J*(J_{norm})_2 & W_L*(L_{norm})_2 \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ W_{CB}*(CB_{norm})_N & W_B*(TB_{norm})_N & W_{AB}*(AB_{norm})_N & W_U*(U_{norm})_N & W_D*(D_{norm})_N & W_J*(J_{norm})_N & W_L*(L_{norm})_N \end{pmatrix} \tag{3.6}$$

Step 5. The next step is to find the best and the worst value for each of the attribute. Depending on the attribute, the best (or the worst) value can be either the maximum or the minimum value. For example, in the case of attribute for network utilization, the best value is the lowest and the worst value is the highest. However, for the case of cost per byte related attribute, the best value is the lowest and the worst value is the highest. In the case of CB, this calculation in general can be represented mathematically as follows:

$$CB_{Best} = \left(\mathrm{Min}\left((\mathrm{CB}_{w-norm})\mathrm{i}\right)\right) \qquad \mathrm{i} = 1,2, \ldots \ldots . . \mathrm{N}$$

$$CB_{Worst} = \left(\mathrm{Max}\left((\mathrm{CB}_{w-norm})\mathrm{i}\right)\right) \qquad \mathrm{i} = 1,2, \ldots \ldots . . \mathrm{N} \qquad (3.7)$$

Step 6. For each of the access network under consideration (represented by a row in the matrix), the measure of separation, both for the best and the worst cases, is calculated

$$S_{Best} = \sqrt{\begin{pmatrix} ((CB_{w-norm})_i - CB_{Best})^2 + ((TB_{w-norm})_i - TB_{Best})^2 + ((AB_{w-norm})_i - AB_{Best})^2 \\ +((U_{w-norm})_i - U_{Best})^2 + ((D_{w-norm})_i - D_{Best})^2 + ((J_{w-norm})_i - J_{Best})^2 \\ +((L_{w-norm})_i - L_{Best})^2 \end{pmatrix}}$$

$$S_{Worst} = \sqrt{\begin{pmatrix} ((CB_{w-norm})_i - CB_{Worst})^2 + ((TB_{w-norm})_i - TB_{Worst})^2 + ((AB_{w-norm})_i - AB_{Worst})^2 \\ +((U_{w-norm})_i - U_{Worst})^2 + ((D_{w-norm})_i - D_{Worst})^2 + ((J_{w-norm})_i - J_{Worst})^2 \\ +((L_{w-norm})_i - L_{Worst})^2 \end{pmatrix}}$$

(3.8)

These equations evaluate the best value for CB (being the minimum) and the worst value for CB (being the maximum).

Step 7. For each of the access networks under consideration (represented by a row in the matrix), its level of preference is measured. The preference level '*P*', measured in terms of distances '*S*' from the best and the worst solutions, is represented by the following formulation

$$\boldsymbol{P_i} = \frac{\boldsymbol{S_{Worst}}}{\boldsymbol{S_{Best+}S_{Worst}}} \qquad (3.9)$$

Step 8. The access network with the highest '*P*' value is selected.

3.2.1. Case study: In order to analyze the use of the TOPSIS approach, four networks have been considered. Table 3.1 presents an attribute values for these networks at the time of network selection. The weights assigned to the attributes used in TOPSIS are based on a subscribed QoS profile stored in user's home operator network.

Table 3.1: Attribute values for the candidate networks.

Networks / Attributes	CB (%)	TB Mbps	D ms	L (per 10^6)
Ntwk 1 UMTS	100	2	400	100
Ntwk 2 WLAN (802.11 b)	20	11	200	20
Ntwk 3 GPRS	90	1	300	150
Ntwk 4 WiMAX	30	100	100	15

We consider a case study addressing generic service i.e. a streaming service. As a streaming service needs to behave well while in operation, the importance of the dynamic criteria (delay, losses) is in general higher than the importance of the static ones (bandwidth, cost), We now look at a scenario in which a streaming service has the possibility to use either WLAN, WiMAX, UMTS and GPRS. Subscription was assumed in this example which indicates an overall lower priority user subscription where delay is significantly important compared with any QoS parameters for the candidate network to be selected. The actual weights assigned to the attributes as per step 3 are shown in Fig. 3.1.

Very high weight has been assigned to delay, whereas the packet losses and total bandwidth have been assigned a lower weight and cost per byte is assigned the least weight. Weights allotted to the attribute values indicate their respective role in network selection for a user.

The results of implementation of TOPSIS for network selection have been tabulated in table 3.2. It is observed that network 4 has the highest preference value (P) so it is ranked 1 and selected the best among all or we can say that it is the most preferred network among the all networks present in heterogeneous environment as it is having the least delay though we have assigned maximum weight to 'delay' for network selection criteria. Next preferred network is network 2 i.e. WLAN then network 3 i.e. GPRS and then follows network 4 i.e. UMTS according to their respective preferences values.

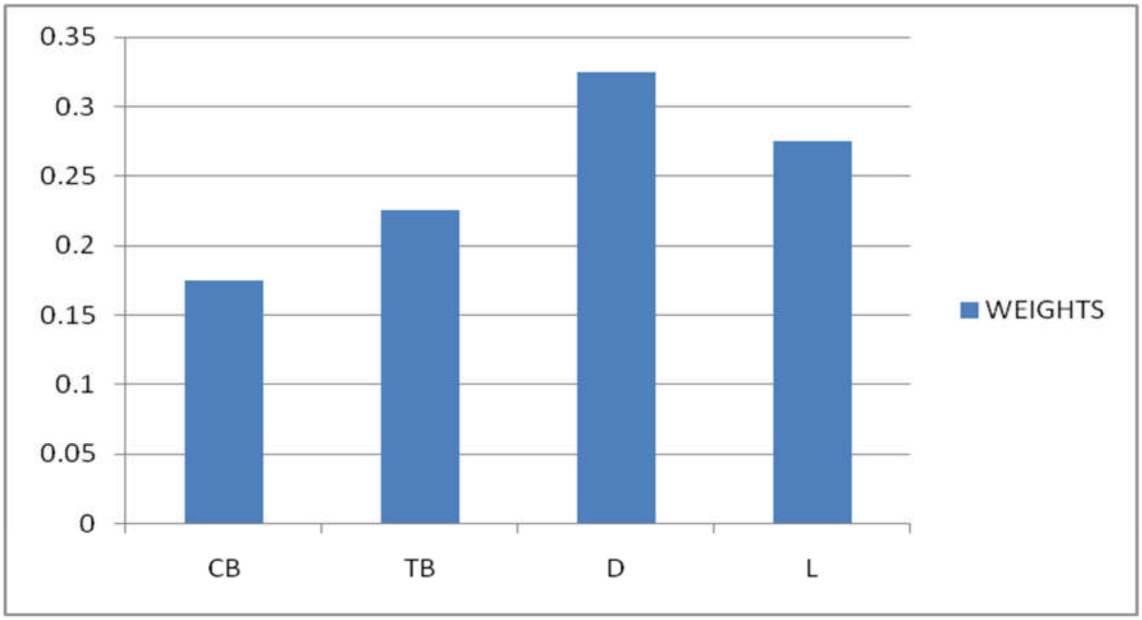


Figure 3.1: Assignment of weights to attribute values for a user in the home operator network

Table 3.2: Results of implementation of TOPSIS technique for network selection in heterogeneous environment

Ntwk#1 (UMTS)	Ntwk#2 (WLAN)	Ntwk#3 (GPRS)	Ntwk#4 (WiMAX)
0.18866 Rank-4	0.55019 Rank-2	0.19228 Rank-3	0.9565 Rank-1

3.3. Network selection based on weight estimation of QoS parameters

A novel algorithm for optimal network selection is proposed in which weight estimation for the representative set of the network attributes is computed using entropy and TOPSIS approach. A heterogeneous environment consisting of four networks, UMTS, WLAN, GPRS and WiMAX, is considered. We investigate the mechanism for the optimal selection of weights in a multi-objective function defined for network selection in a heterogeneous environment. The multi-objective function consists of dominant parameters such as bandwidth, delay, packet loss and cost. These parameters particularly characterise the performance of voice, video and data services. A typical scenario faced by triple play services is shown in Fig. 3.2. The weight coefficients are adjusted depending on the demand of multimedia services. The weight equation is modeled for optimal radio access network selection using the threshold values of dominant parameters.

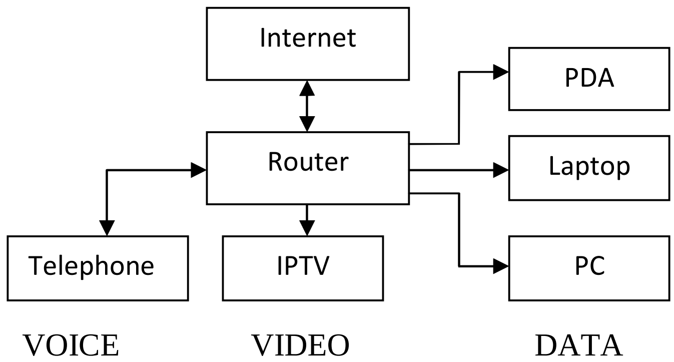


Figure 3.2: Typical triple-play service setup

3.3.1. Proposed network selection algorithm: We consider a heterogeneous network consisting of four wireless systems- UMTS, WLAN, GPRS, and WiMAX. The multimode user terminal retains a set of available networks based on the criterion of the RSS threshold. We define a multi objective function consisting of four QoS parameters, namely, bandwidth, delay, packet loss and cost. The first attribute D is the average packet delay within the access system, BW indicates the total bandwidth provided by the access node and L measures the average packet loss within the access system. The cost parameter (CB) is defined as the data transfer cost per byte to be charged by the operator. The Multi Objective Function (MOF) is defined as

$$MOF=W_1 \times D+ W_2 \times BW+ W_3 \times L+ W_4 \times CB \tag{3.10}$$

$$W_1+W_2+W_3+W_4 = 1 \tag{3.11}$$

Where, Wi; i=1,...,4 are the normalised weights assigned to delay, bandwidth, packet loss and cost parameters respectively. Sum of all normalised weights is equal to unity [70]. The weights are initialised by using entropy [126]. Then, the weights are varied using a step size of 0.05, resulting in various combinations of different weight values.

A graphical representation of possible weight combinations for a given step size is shown in Fig. 3.3.

The weight combinations are assigned in proportion to the requested services. Voice service is delay sensitive and has a low bandwidth requirement. It can also tolerate packet loss to a certain extent. Moreover, the cost parameter in the case of voice service is not a major factor. In the case of video applications, packet loss not only leads to reduced quality of the frame but also results in the propagation of distortion to successive frames. Video sequences place the heaviest load on network infrastructures because of the greater demand for bandwidth, whereas cost and packet loss are more vital parameters for data service.

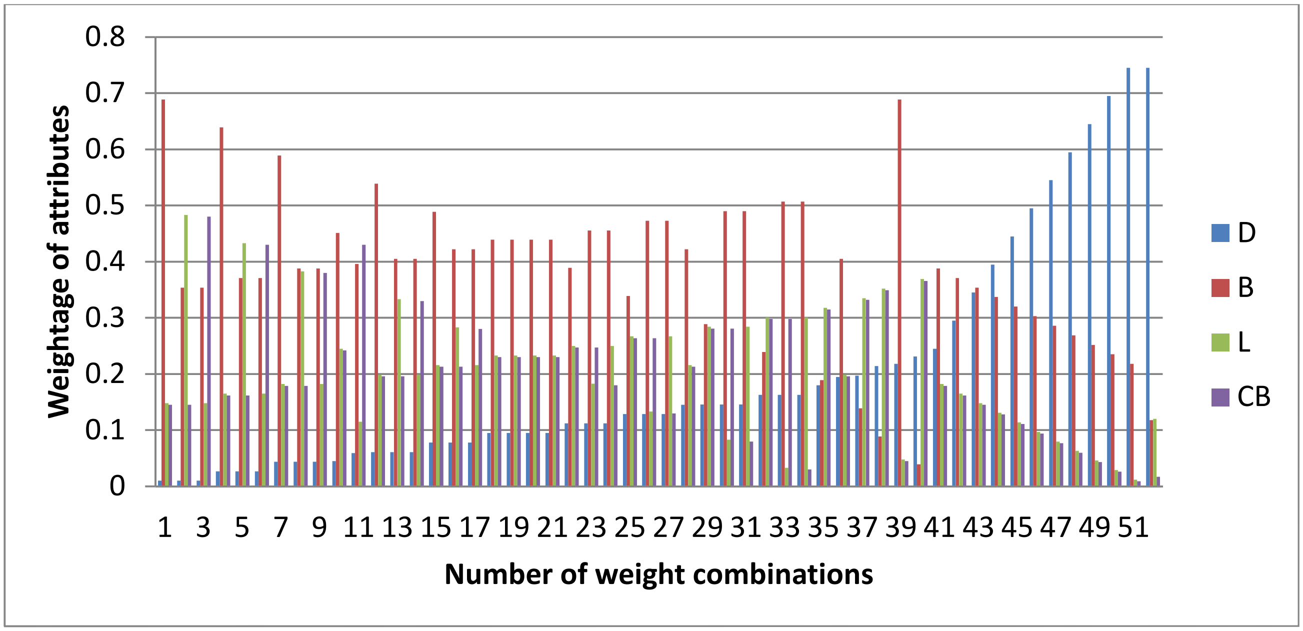


Figure 3.3: Various weight combinations of dominant parameters.

Standard threshold values for the dominant parameters of triple play services, as presented in Table 3.3, are considered to formulate the weight equation from the various weight combinations [10, 127].

In the case of the transmission of lower quality conversational voice services, the utmost tolerable network delay is 150 ms, which is considered as a threshold value for the maximum delay for voice service, above which voice communication is not possible. Bandwidth, cost and packet loss are the other dominant parameters for voice service. Video service requires a minimum bandwidth of 768 Kbps for video conferencing, below which video conferencing is not feasible. Other dominant parameters in the case of video are delay, packet loss and cost.

In the case of data service, the cost is a crucial parameter, whereas the other parameters, in order of dominance, are bandwidth, packet loss and delay.

Table 3.3: Threshold values to select weights

Triple service	QoS Parameters			
	Delay	Bandwidth	Packet Loss	Cost
Voice	150 ms	64Kbps	<1% to 3%	0.10 paise/sec
Video	400 ms	768 Kbps	<1%	Rs. 10./KB
Data	10 sec	9.6Kbps	<1% to 10%	Rs. 5/KB

A flow chart of the proposed algorithm is shown in Fig. 3.4. In the first stage, the selection process is triggered by several conditions, such as the generation of a new service, changes in user profiles or the detection of a newly available access point. Then certain parameters used in the network selection procedure are collected such as radio propagation conditions, the load situation in each radio access network, the required QoS level according to the service, the achievable level of QoS per radio access network, the consumed resources, the corresponding charge per radio access network, etc. In the second stage, the weight of each parameter is calculated. The calculated weight factors reflect the dominance of each requirement with respect to the user and the service.

3.3.1.1. Implementation: This section describes the proposed weight assignment algorithm along with entropy for weight initialization and TOPSIS [126] techniques to objectively decide the best solution for network selection.

The process of vector normalisation was employed to compare the attributes of different values and different units of measurement such that the starting matrix $\|x_{ij}\|_{nx4}$ (Table 3.4) becomes the normalised matrix $\|r_{ij}\|_{nx4}$, where

$$r_{ij} = x_{ij}/\sqrt{\sum_{i=1}^{n} x_{ij}^2}, \; r_{ij} \epsilon [0\ 1] \tag{3.12}$$

3.3.1.1.1. Weight initialization using entropy method: We have used entropy method for weight initialisation. As it is more accurate and is convenient to implement [126]

Algorithm of entropy method for defining the weighted coefficients:

***Step* 1:** It is necessary to transform the model such that all the attributes must be maximized. The relations in the model remain unchanged, but the nature of the criteria for delay, packet loss and cost changes (min → max) in the following operation: $x^*_{i1} = 1- x_{i1}$, $x^*_{i3} = 1- x_{i3}$ & $x^*_{i4} = 1- x_{i4}$ for each $i \in \{1, 2,\ldots\ldots,n\}$.

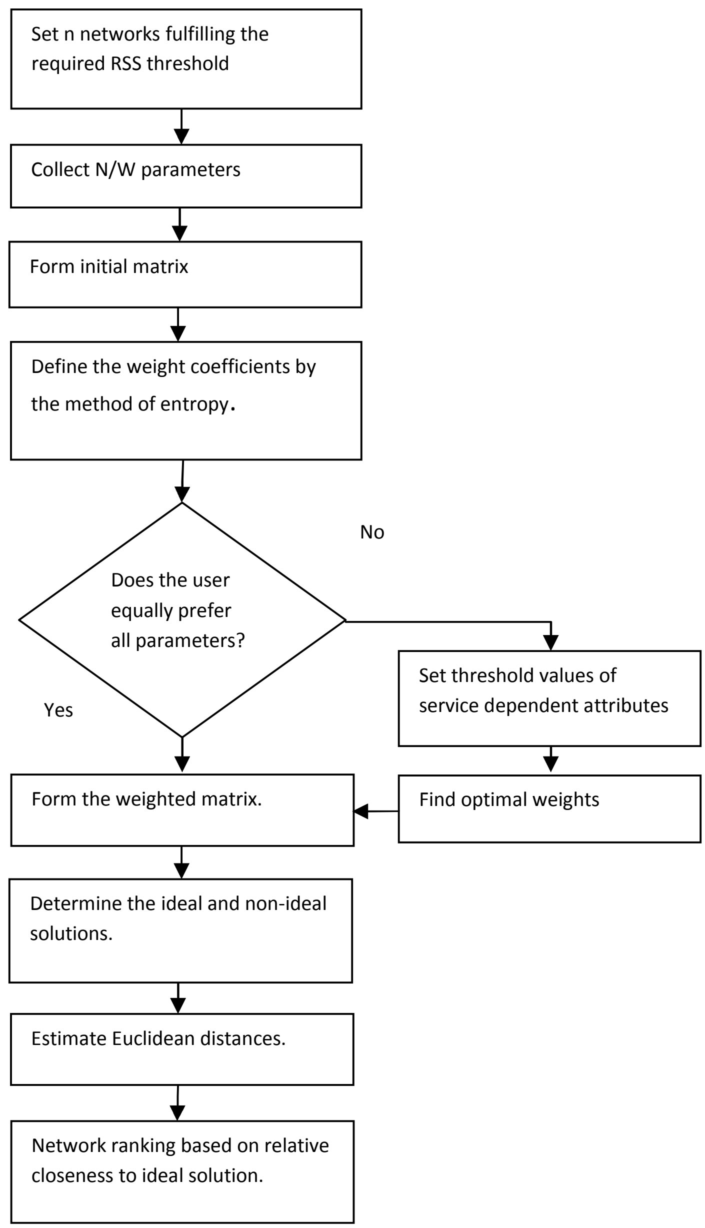


Figure 3.4: The algorithm for the optimal network selection.

***Step* 2:** Determine the entropy of the attributes based on the relation

$$e_j = \left[\frac{-1}{\ln(n)}\right] \times \sum_{i=1}^{n}\left[r_{ij}\ln(r_{ij})\right] \quad j \in \{1, 2, 3, 4\} \qquad (3.13)$$

Table 3.4: The starting matrix for the model

Networks / Attributes	D (ms)	BW (Mbps)	L (per 10^6)	CB (%)
	Min	Max	Min	Min
Net_1	x_{11}	x_{12}	x_{13}	x_{14}
Net_2	x_{21}	x_{22}	x_{23}	x_{24}
Net_i	x_{31}	x_{32}	x_{33}	x_{34}
Net_n	x_{41}	x_{42}	x_{43}	x_{44}
W_j	W_1	W_2	W_3	W_4

***Step* 3:** Determine the deviation within each criterion:

$$d_j = 1 - e_j, \text{ for } j \in \{1, 2, 3, 4\} \qquad (3.14)$$

***Step* 4:** Determine the weight coefficients:

If the user equally prefers all the parameters,

$$W_j = \frac{dj}{\sum_{j=1}^{4} dj} \qquad (3.15)$$

If the user determines the subjective weights,

$$W_j = d_j w_j / \sum_{j=1}^{4} d_j w_j \qquad (3.16)$$

Where w_j is the weight selected according to the service.

After determining the initial weight coefficients using the entropy method, the weights are computed for the requested service using equation (3.17).

$$\begin{pmatrix} weight \\ Estimation \\ of\ requested\ service \end{pmatrix} == \begin{pmatrix} Weight\ combinations\ of \\ QoS\ parameters \\ initialized\ through\ entropy \end{pmatrix} \times \begin{pmatrix} Threshold \\ values\ of\ attributes\ of\ the \\ requested\ service \end{pmatrix} \quad (3.17)$$

3.3.1.1.2. Network selection using TOPSIS method: The TOPSIS algorithm is based on the assumption that the chosen solution has the shortest distance from the best solution but the longest distance from the worst solution. The following steps are involved in the application of TOPSIS to the network selection problem.

Table 3.5: Attribute values for the radio access networks.

Networks / Attributes	D (ms)	BW (Mbps)	L (Per 10^6)	CB (units)
Net 1 UMTS	400	2	100	100
Net 2 WLAN (802.11 b)	200	11	20	20
Net 3 GPRS	300	1	150	90
Net 4 WiMAX	100	100	15	30

Algorithm of TOPSIS method for network selection

As described in section 3.2, Here, the weighted matrix $\left\| V_{ij} = W_j . r_{ij} \right\|_{n \times 4}$ is created to implement TOPSIS. V_{ij} represents the updated weight matrix, i.e., the multiplication of the weight coefficients matrix generated by the entropy method and the proposed weight assignment algorithm with the normalised weight matrix. Thus, the ideal solution is given as

$$A^+ = \{(\max V_{ij} | j \epsilon J); (\min V_{ij} | j \epsilon J^{'})\} \quad (3.18)$$

Where J is the set of criteria that are being maximised and J' is the set of criteria that are being minimised. This model is transformed while finding the weight coefficients such that all the maximized parameters are based on that relation as well. The ideal solution in this case is written as

$$A^+ = \{(\max V_{ij} | J \epsilon \{1,2,3,4\})\} \quad (3.19)$$

Analogous to (3.19), the non-ideal solution is the set

$$A^{-} = \{(\min V_{ij} | J \epsilon \{1,2,3,4\})\} \quad (3.20)$$

The Euclid alternative distances, in relation to the ideal and non-ideal solutions, are determined by

$$D_i^{+} = \sqrt{\sum_{J=1}^{4} (V_{ij} - V_j^{+})^2} \quad (3.21)$$

$$D_i^{+} = \sqrt{\sum_{J=1}^{4} (V_{ij} - V_j^{-})^2} \quad (3.22)$$

Finally, the ranking of networks is performed by considering the relative closeness to the ideal solution, expressed as

$$D_i = \frac{D_i^{-}}{D_i^{-} + D_i^{+}} \quad (3.23)$$

where, the best network is the one with the largest relative closeness to the ideal solution.

3.3.2. Results and discussion: Four networks are considered to analyze the impact of entropy, the TOPSIS approach and the threshold weight estimation criteria for triple play services. Table 3.5 presents the attribute values for these networks at the time of network selection. The weights assigned to the attributes used in TOPSIS are based on a subscribed QoS profile stored in the user's home operator network.

Table 3.6: Normalised matrix

Networks/ Attributes	D	BW	L	CB
UMTS	0.27	0.019	0.451	0.822
WLAN (802.11 b)	0.635	0.109	0.891	0.856
GPRS	0.452	0.009	0.176	0.354
WiMAX	0.817	0.994	0.918	0.785

According to step 1, the normalisation of the attribute values is performed for all of the attributes with different measurement units. Table 3.6 represents the normalised matrix of various attributes. After normalisation, the weight equation is generated by employing the initialised weights generated by entropy. Table 3.7 represents the initialised weight matrix, and Fig. 3.5 presents a graphical representation of these weights.

Table 3.7: Weighted matrix with the initialised weights calculated by entropy

Networks / Attributes	D	BW	L	CB
Weights	W_1	W_2	W_3	W_4
W_j	**0.105**	**0.48**	**0.255**	**0.16**
UMTS	0.026	0.008	0.105	0.189
WLAN (802.11 b)	0.060	0.048	0.208	0.197
GPRS	0.043	0.004	0.041	0.081
WiMAX	0.078	0.436	0.214	0.181

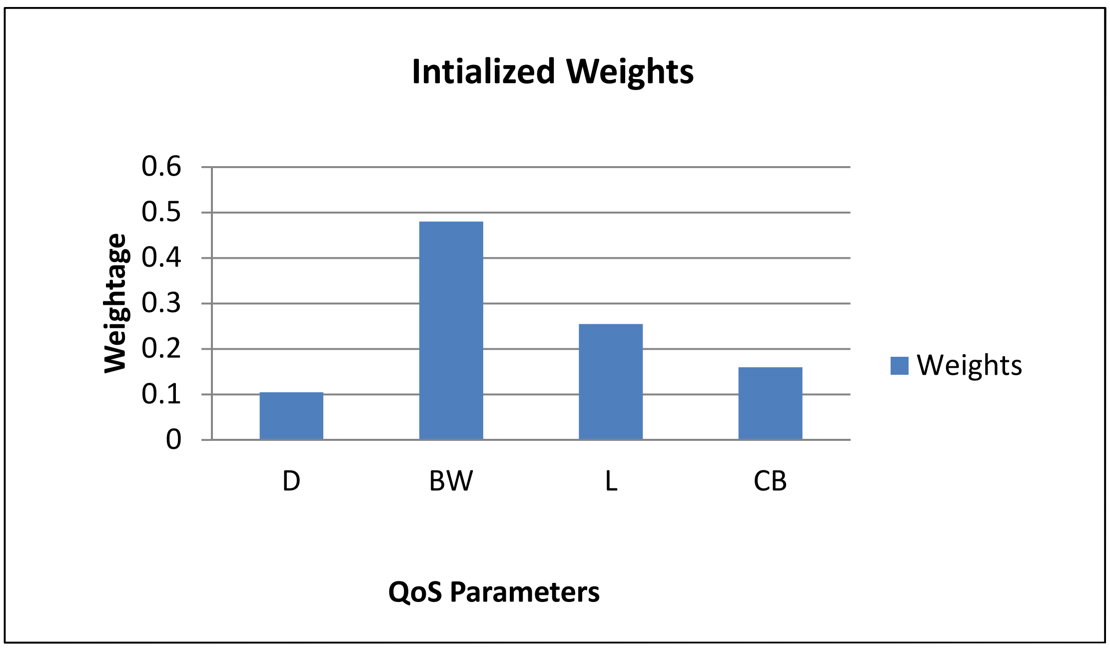


Figure 3.5: The initialised weights generated by entropy

As per the proposed algorithm, the weights are assigned according to the service or user demand, as shown in Fig. 3.6. The proposed algorithm is implemented for three scenarios employing triple play services on four available access networks, UMTS, WLAN, GPRS and WiMAX.

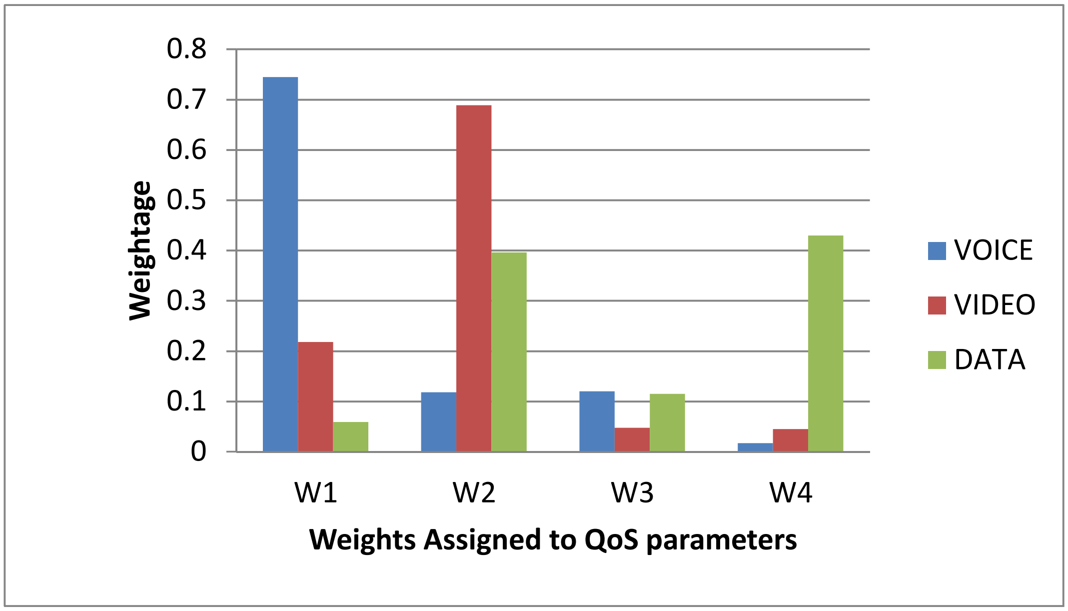


Figure 3.6: Weights selected according to the triple service QoS parameters using the threshold values

After finding the weight coefficients using the threshold method, the weighted matrix for triple play services is determined using TOPSIS. Table 3.8 shows the weighted matrix for voice service, and Fig. 3.7 provides a graphical representation of it.

Table 3.8: Weighted matrix for voice service

Networks / Attributes	**D**	**BW**	**L**	**CB**
Weights	W_1	W_2	W_3	W_4
W_j	**0.745**	**0.118**	**0.12**	**0.017**
UMTS	0.201	0.002	0.054	0.014
WLAN (802.11 b)	0.473	0.013	0.107	0.015
GPRS	0.337	0.001	0.021	0.006
WiMAX	0.609	0.117	0.110	0.013

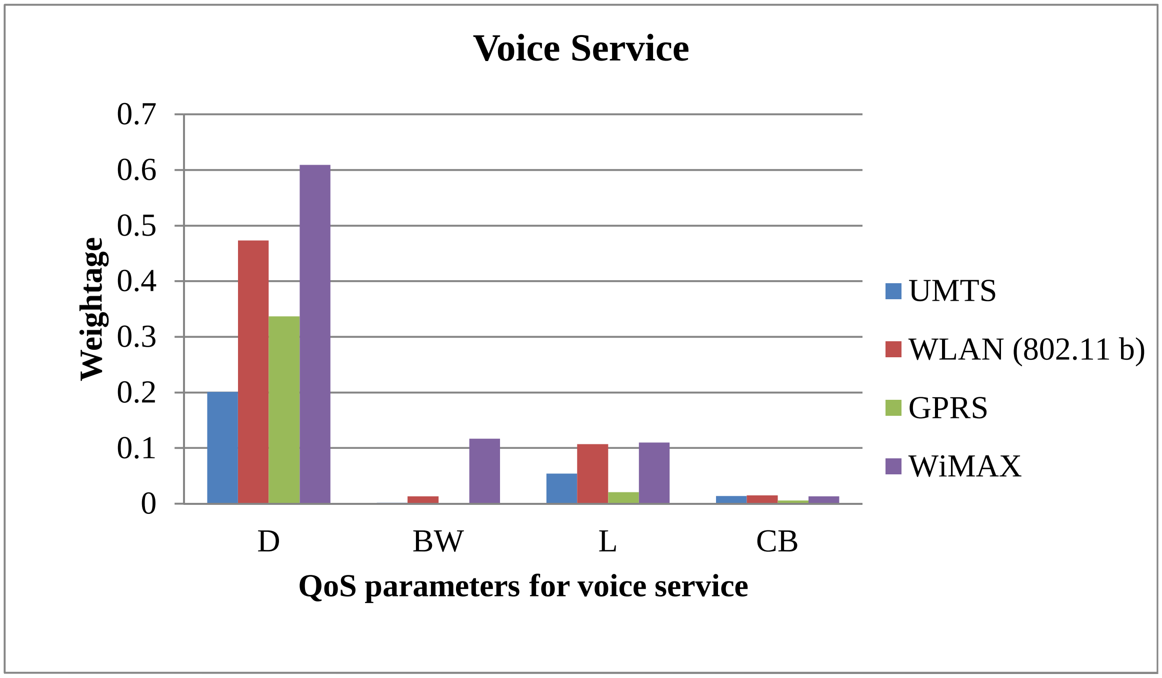


Figure 3.7: Radio access network selection based on voice service using delay as the dominant parameter

According to first service (voice), the user's preference lies in minimum delay, and the weight coefficient W_1 = 0.745 is determined for this parameter through weight assignment. Table 3.8 shows that Net3 (GPRS) is an optimal network based on BW, L and CB, even though the delay in the case of Net1 (UMTS) is marginally low.

In the case of video service, bandwidth is the dominant parameter. W_2 = 0.689 is determined by the threshold video bandwidth based on the service demands. In addition, the bandwidth the delay parameter (W_1 = 0.218) is also proved to be important for this application, whereas the packet loss (W_3 = 0.048) and cost (W_4 = 0.045) are of less significance. Based on bandwidth, Net4 emerges as an optimal access network for video service. The test results obtained for video services are shown in Table 3.9 and Fig. 3.8.

The user requires the lowest data cost for data service, and thus, the weight coefficient W_4 = 0.43 is set in combination with the service demand for this parameter. It can be concluded from the results that Net2 has the lowest data transfer cost (Table 3.10 and Fig. 3.9).

However, Net1 is declared as the optimal network because it provides much better QoS, i.e., low delay and packet loss.

Table 3.9: Weighted matrix for video service

Networks / Attributes	D	BW	L	CB
Weights	W_d	W_{bw}	W_L	W_{cb}
W_j	**0.218**	**0.689**	**0.048**	**0.045**
UMTS	0.059	0.013	0.022	0.037
WLAN (802.11 b)	0.138	0.075	0.043	0.039
GPRS	0.099	0.006	0.008	0.016
WiMAX	0.178	0.685	0.044	0.035

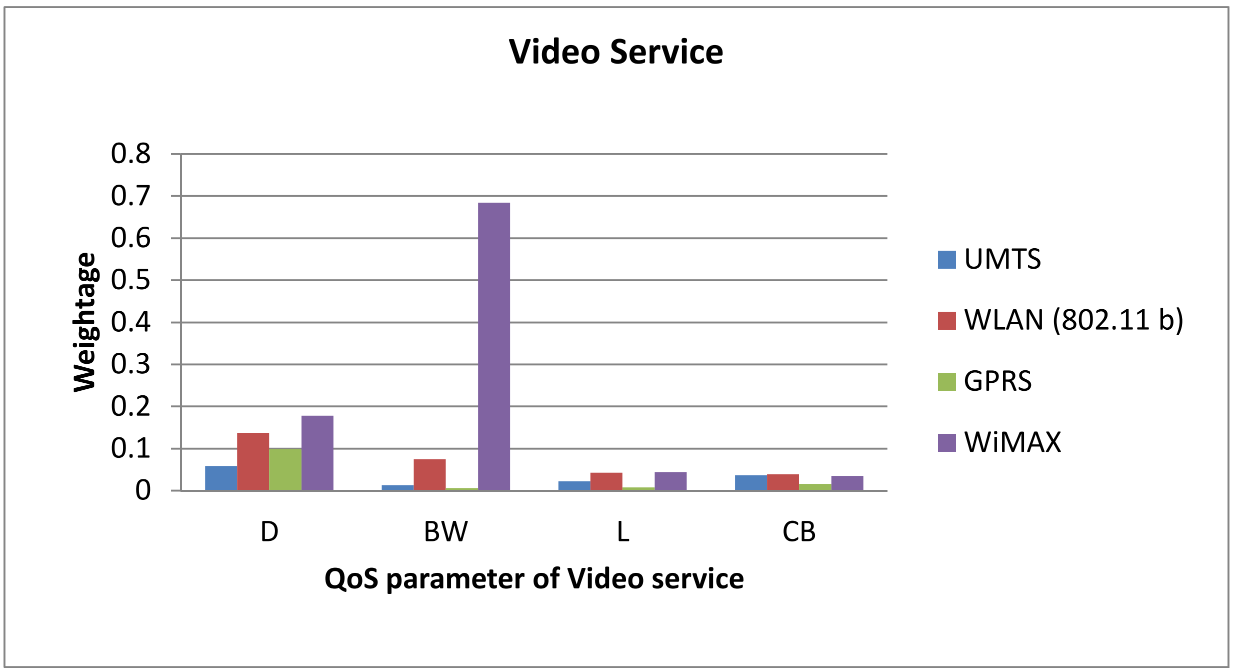


Figure 3.8: Radio access network selection based on video service using bandwidth as the dominant parameter.

3.3.2.1. Performance evaluation of the proposed algorithm based on QoS parameters: Fig. 3.10 shows the results obtained when the same set of weight parameters were applied to the networks considered. It is evident that all of the networks yield different levels of performance even with the same set of attributes, and thus, the choice of the optimal network is subject to the user or service demands for triple-play services.

Table 3.10: Weighted matrix for data service

Networks / Attributes	D	BW	L	CB
Weights	W_d	W_{bw}	W_L	W_{cb}
W_j	**0.059**	**0.396**	**0.115**	**0.43**
UMTS	0.016	0.007	0.051	0.353
WLAN (802.11 b)	0.037	0.043	0.102	0.368
GPRS	0.027	0.004	0.020	0.152
WiMAX	0.048	0.394	0.106	0.338

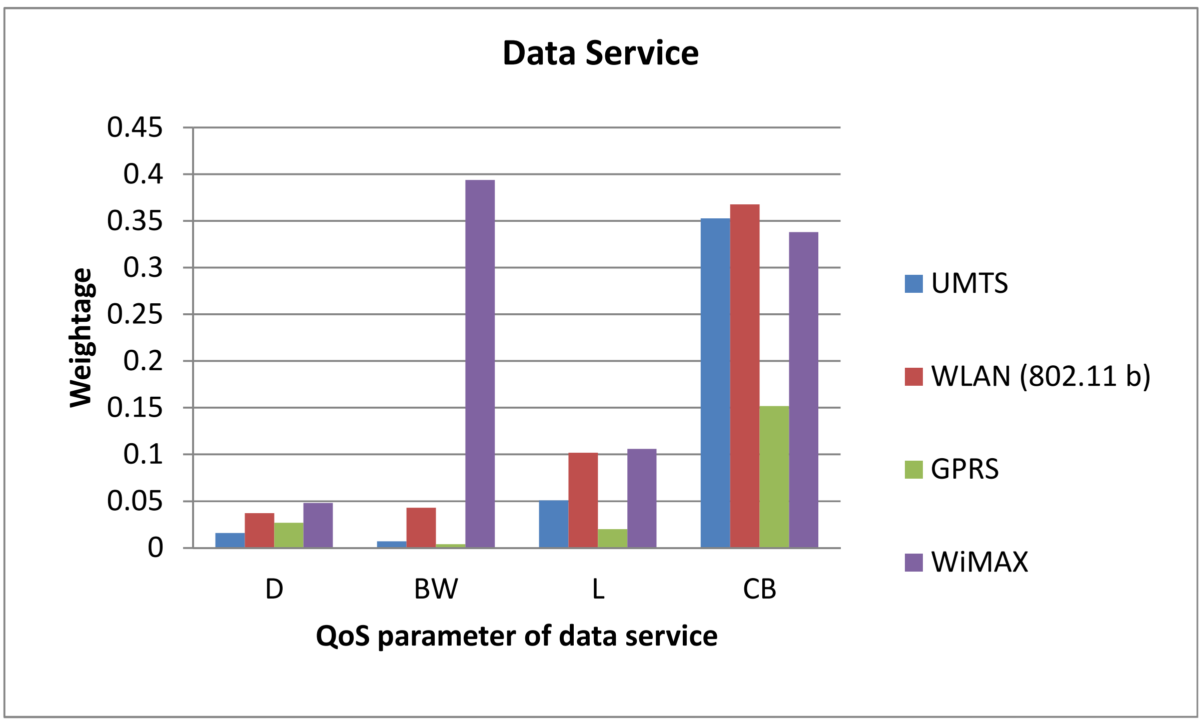


Figure 3.9: Radio access network selection based on data service using cost as the dominant parameter.

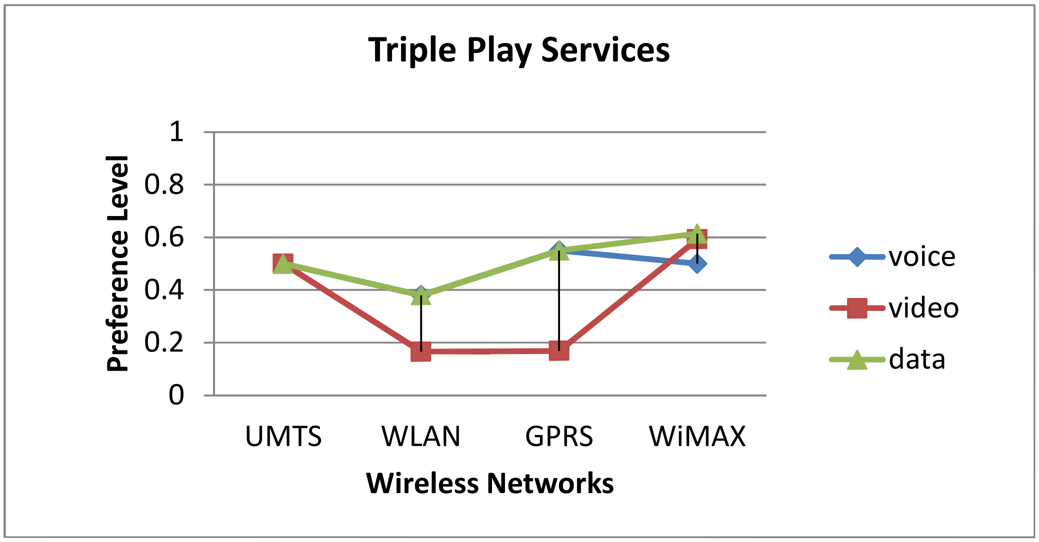


Figure 3.10: Optimal network selected for triple play services

3.3.2.2. Sensitivity of network selection to dynamic attribute values: Various scenarios employing triple play services are considered to evaluate the performance of the proposed algorithm, as discussed below.

Case 1: In this case, we assume that the operator of the WiMAX network has temporarily indicated a decrease in access cost to the subscriber to attract more customers to its network, as shown in Fig. 3.11. As a result, when the network's ranking is computed, this network becomes attractive for most of the services or users for whom cost is an important factor in the decision process.

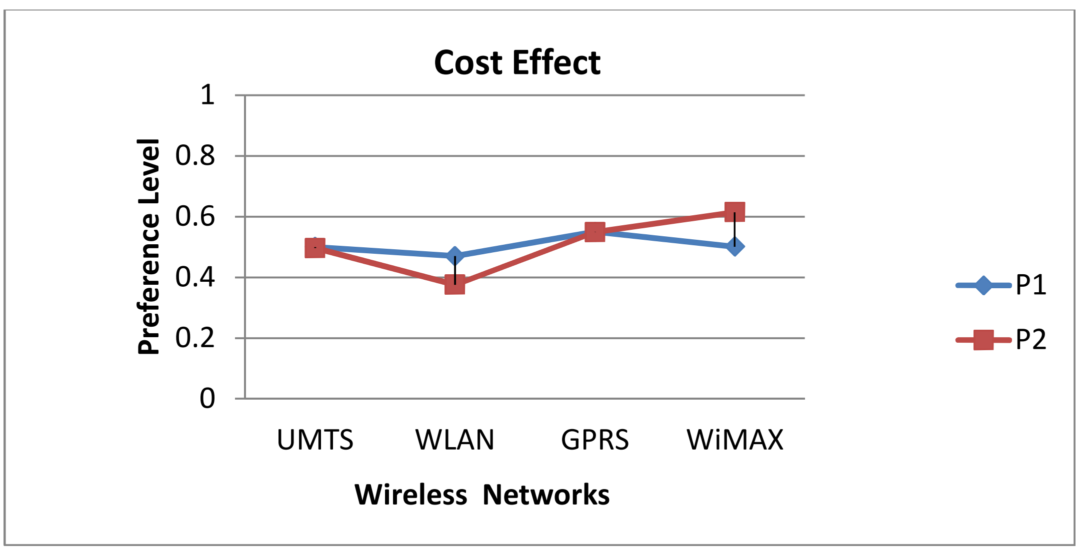
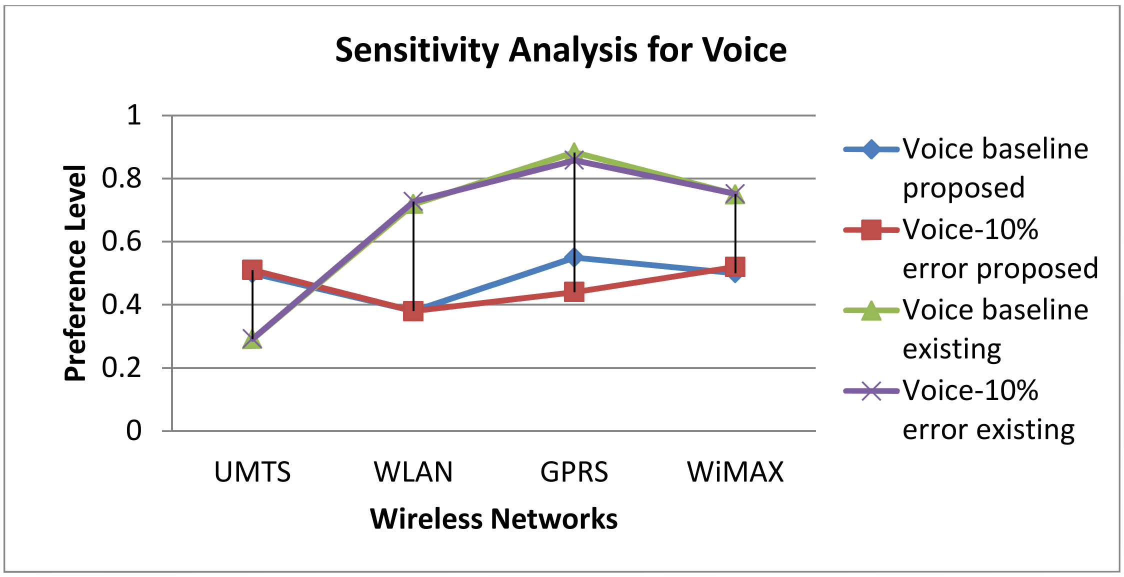
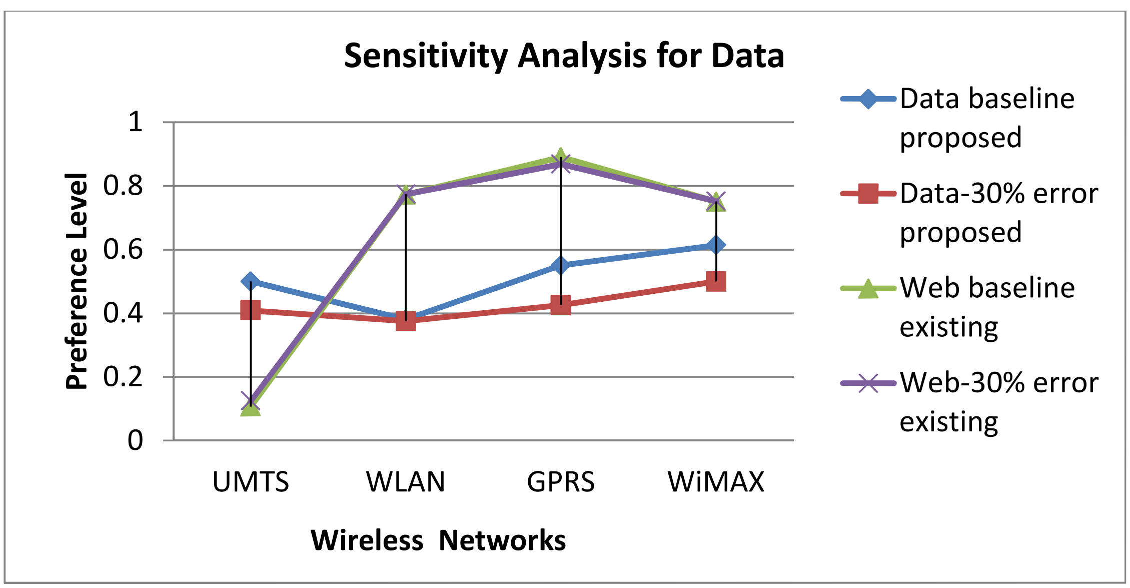


Figure 3.11: Effects of the cost attribute on network selection.

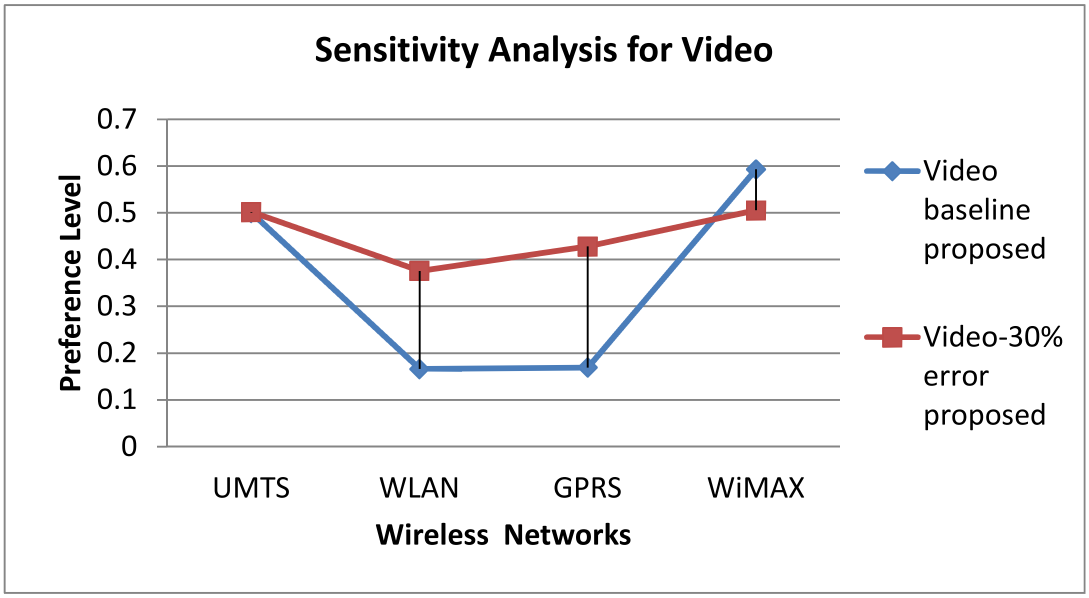
Case 2: In the second case, the previously described attribute values for delay are altered by 10% for voice users and 30% each for data and video users. The results indicate that, although a 10% change in this attribute value changes the selected network for a voice user, a change of even 30% in this attribute value does not influence the selection of a data and video user, as shown in Fig. 3.12. Thus, network selection for data or video are less sensitive to the delay attribute than that for voice services due to the assignment of lower weights to the delay attribute in the QoS profile for data and video services.



(a)



(b)



(c)

Figure 3.12: Sensitivity of network selection to the dynamic attribute values for triple- play services: **(a)** voice **(b)** data **(c)** video

Consequently, errors in these attribute values have a comparatively lower impact on network selection, thus yielding more reliable results, which attests the robustness of the proposed algorithm. The results of the algorithm are in close agreement with the findings reported in [127], which further justifies the validity of this algorithm.

3.4 Profile matching based network selection algorithm

It is important to evolve a method that takes into account user preferences, network conditions and QoS in order to select the optimal network and also achieves the best balance between user and network performance. The network selection method must incorporate the use of parameterized network and user profiles in order to model diverse QoS flexibility for different real time and non-real time applications. In this section, we propose a more scalable and flexible approach. The approach is based on profiles of both network and user. Profiles provide flexibility in terms of choosing the factors to be considered in network selection decision. Depending on the information availability for the decision making from the underlying wireless technologies, profiles can be customized accordingly. In particular, on the basis of profiles, we propose a network selection scheme for multi service heterogeneous wireless networks. In the proposed scheme, multi service traffic classes are handled. The proposed scheme can be implemented in a distributed manner.

3.4.1. Proposed network selection algorithm: Proposed algorithm of network selection is executed in two phases. At first, profiles are generated for users and networks. The user/ network profile represents the relative status of a user/network as compared to other in terms of traffic demand. The best match between user and network is determined by considering their profiles.

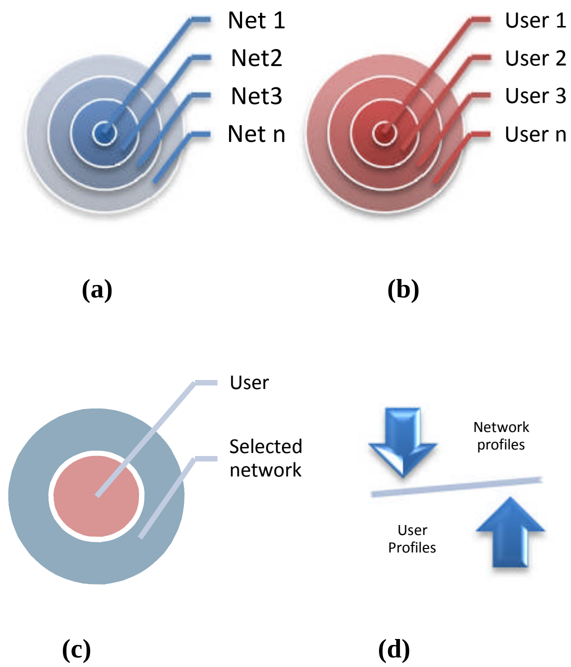


Figure 3.13: (a) Network profiles **(b)** user profiles **(c)** and **(d)** represents counter balance between network profiles and user profiles to select the best suitable network according to user's service.

A profile is composed of n profile values, each of which corresponds to a category. To represent the integral view of the status of a user/network, profile space is used, which is an n dimensional space where each axis is mapped to each category. The categories are classified into two types, dynamic and static categories. The factors in dynamic categories are changed as a result of network selection decision while those in static categories are invariant. Currently, three categories under consideration include traffic status, mobility, and QoS for both user/network profiles. However, more categories can be added.

3.4.1.1. Network profile: Network profiles represent the relative status of the networks in X which is the list of currently accessible networks. For network profiling, each network is projected on a multi-dimensional profile space, in which each axis is mapped to a profile category. For each category, one or many factors about the network's current status are collected from the networks in X. The collected factor values are normalized into a range of [S_{min}, S_{max}] as shown in Eq. (3.24). Through normalization, only the relative magnitude relationships are retained.

$$p_{c,i} = (s_{\max} - s_{\min})(\frac{(\lambda_{c,i} -_{\min}(\lambda_{c,\chi}))}{(_{\max}(\lambda_{c,\chi}) -_{\min}(\lambda_{c,\chi}))}) + s_{\min} \tag{3.24}$$

For some categories of user/network, the order of the values need to be reversed as follows.

$$p_{c,i} = s_{\max} - (s_{\max} - s_{\min})(\frac{(\lambda_{c,i} -_{\min}(\lambda_{c,\chi}))}{(_{\max}(\lambda_{c,\chi}) -_{\min}(\lambda_{c,\chi}))}) \tag{3.25}$$

Where, p $_{c,i}$ denotes the profile value of the i for category c. $\lambda_{c,i}$, and $\lambda_{c,\chi}$ represents the value of a factor of network i or a set of them in χ, for category c. Min ($\lambda_{c,\chi}$) and max ($\lambda_{c,\chi}$) indicate the minimum and maximum values among $\lambda_{c,\chi}$. When there is more than one factor in a category, the summation of the profile values of each factor is computed while applying the weight that specifies the relationship among the factors. The relative maximum value ($\lambda_{c,\chi}$) and minimum value ($\lambda_{c,\chi}$) of factors with respect to the other users/networks are calculated by as follows.

Step 1: Calculate the mean variance of every factor which reflect the absolute degree of variation by D

$$D = \sqrt{\sum_{i=1}^{m} \frac{(x_{ij} - \overline{x_j})^2}{n}} \tag{3.26}$$

$$\overline{x_j} = \sum_{i=1}^{m} \frac{x_{ij}}{n} \tag{3.27}$$

x_j = The mean value of j factor having i number of elements.

Step 2: Calculating the co-efficient of variation c_j of every factor to reflect the relative degree of variation.

$$c_j = \frac{D_j}{\overline{x_j}} \tag{3.28}$$

Step 3: Normalizing the coefficients of variation of every factor to achieve the overall weight of every factor.

$$w_j = \frac{c_j}{\sum_{j=i}^{m} c_j} \tag{3.29}$$

From w_j we can find min ($\lambda_{c,\chi}$) and max ($\lambda_{c,\chi}$).

Network profile consists of three categories i.e. traffic, mobility and QoS with their respective factors

a. Traffic: For the traffic status category of the network profile, we use the available capacity of a network. When the profile value of a network is closer to S_{max} than other networks, it indicates that the network has more capacity left for the newly coming real time users than other networks. λ_{ac} will be determined by the current traffic load level of the cell and the admission control policy used. The profile value of traffic status category, $p_{t,i}$, is computed by Eq. (3.30) with $\lambda_{ac,i}$ and $\lambda_{ac,\chi}$ replacing $\lambda_{c,i}$ and $\lambda_{c,\chi}$, respectively.

$$p_{t,i} = (s_{\max} - s_{\min})\left(\frac{(\lambda_{ac,i} - \min(\lambda_{ac,\chi}))}{(\max(\lambda_{ac,\chi}) - \min(\lambda_{ac,\chi}))}\right) + s_{\min} \tag{3.30}$$

b. Mobility: For the mobility category of the network profile, we use the size of the network's coverage. The network size is used since it determines the frequency of handover. Fast moving users would prefer the networks with the large mobility profile value. On the contrary, slow moving users would concern less on the mobility profile value. $\lambda_{Cov,i}$ and $\lambda_{Cov,X}$ denotes the coverage (i.e., network radius) of network *i* and that of the networks in *X* respectively. The profile value for mobility category, $p_{m,i}$ is computed by Eq. (3.31) with $\lambda_{Cov,i}$ and $\lambda_{Cov,X}$ replacing $\lambda_{c,i}$ and $\lambda_{c,X}$, respectively.

$$p_{m,i} = (s_{\max} - s_{\min})(\frac{(\lambda_{\text{cov},i} - _{\min}(\lambda_{\text{cov},\chi}))}{(_{\max}(\lambda_{\text{cov},\chi}) - _{\min}(\lambda_{\text{cov},\chi}))}) + s_{\min} \tag{3.31}$$

c. QoS: For the QoS category of the network profile, we use the expected data loss by either network overloading or handover delay. Note that we assume that the requested throughput and average speed of each real time user are known. The user's mean network boundary crossing rate η_b and the handover rate η_h are approximately the same. The handover rate of the user μ is estimated as

$$\eta_{h,i,\mu} \approx \eta_{b,i,\mu} = 2V\mu/\pi r_i \tag{3.32}$$

Where $V\mu$ is the average velocity of the user μ and r_i is the radius of the network i. Then the user's expected sojourn time becomes $1/\eta_{h,i,\mu}$. From this, we can estimate the amount of data loss due to the traffic overload at the network i, $E_{OL,i}$, where $\tau_{rdr,\mu}$ is the requested data rate by user μ, as follows.

$$E_{ol,i} = \frac{\tau_{rdr,\mu} - \lambda_{ac,i}}{\eta_{bi,\mu}} \tag{3.33}$$

The expected data loss for the user μ due to its handover to a cell i, $E_{HO,i}$ is computed by the product of $\tau_{rdr,\mu}$ and the handover delay.

$$E_{ho,i} = \frac{\tau_{rdr,\mu}}{\eta_{bi,\mu}} \tag{3.34}$$

The total expected data loss $\lambda_{E,i}$ is the sum of $E_{OL,i}$ and $E_{HO,i}$.

$$\lambda_{E,i} = E_{ol,i} + E_{ho,i} \tag{3.35}$$

Optionally, RSS, delay, jitter may be considered in computing the QoS profile value. The network with the least expected data loss should have the highest profile value. Therefore, the profile value of QoS category $p_{E,i}$ is computed by Eq. (3.36) replacing factors with $\lambda_{E,i}$ and $\lambda_{E,\chi}$.

$$p_{E,i} = s_{\max} - (s_{\max} - s_{\min})(\frac{(\lambda_{E,i} - \min(\lambda_{E,\chi}))}{(\max(\lambda_{E,\chi}) - \min(\lambda_{E,\chi}))}) \tag{3.36}$$

3.4.1.2. User profile: The user profile represents the relative status of the user μ against other users who can be connected to the networks in *X*. The user profile values are also normalized by using Eqs. (3.24) and (3.25). The information on other users may be collected from the networks in *X* or may be estimated by previously reported statistics.

a. Traffic: For the user profile's traffic status category, the traffic status profile value $p_{t,\mu}$ is computed by Eq. (3.37) with $\tau_{rdr,\mu}$ and $\tau_{rdr,\chi}$

$$p_{t,\mu} = (s_{\max} - s_{\min})(\frac{(\tau_{rdr,\mu} - \min(\tau_{rdr,\chi}))}{(\max(\tau_{rdr,\chi}) - \min(\tau_{rdr,\chi}))}) + s_{\min} \tag{3.37}$$

where $\tau_{rdr,\mu}$ is the requested data rate, the traffic load the user μ is going to create, and $\tau_{rdr,\chi}$ is a set of serviced data rates of the existing users in the list *X*.

b. Mobility: The mobility category of the user profile uses the velocity of the users. $\tau_{v,\mu}$ denotes the user μ's velocity, and $\tau_{v,\chi}$ is a set of velocities of the existing users attached to the networks in *X*. The profile value for the user μ 's mobility axis, $p_{m,\mu}$ is computed by (3.38) with $\tau_{v,\mu}$ and $\tau_{v,\chi}$

$$p_{m,\mu} = (s_{\max} - s_{\min})(\frac{(\tau_{v,\mu} - \min(\tau_{v,\chi}))}{(\max(\tau_{v,\chi}) - \min(\tau_{v,\chi}))}) + s_{\min} \tag{3.38}$$

c. QoS: The QoS user profile represents the user's QoS requirement level. For real time traffic, it means how much data loss the user can tolerate. For obvious reasons smaller value is desirable.

In multi service wireless networks, both real time (RT) traffic and non-real time (NRT) traffic are serviced concurrently by sharing the available network resources. It is assumed that NRT traffic is generated by data transfer applications where the amount of the data is known a priori. Network profile for NRT traffic user is described as follows:

For the network's traffic status profile, the average service data rate per user, $\lambda_{AvgSDR,i}$, is used. All the NRT traffic will share the capacity available for the NRT traffic in a network, which is determined by the admission control policy of the network. For given available capacity for NRT traffic, the average service data rate per user is determined by the NRT traffic scheduling policy (e.g., round-robin) at the network. The profile value of the network *i*'s traffic status, $p_{t,i}$ is computed by Eq. (3.24) with $\lambda_{AvgSDR,i}$, and $\lambda_{AvgSDR,\chi}$ replacing $\lambda_{c,i}$ and $\lambda_{c,\chi}$, respectively. $\lambda_{AvgSDR,\chi}$ denotes a set of average serviced data rates of the networks listed in *X*. The mobility network profile for NRT traffic is identical to that for RT traffic. For the QoS network profile, the ratio of the expected service data rate against the network's capacity is used. It is denoted by $\lambda_{SoC,i,}$ which indicates the expected Share of the Capacity (SoC) the user will take at a network *i*. The QoS network profile of a network *i* is computed by Eq. (3.36) replacing $\lambda_{c,i}$ and $\lambda_{c,\chi}$ with $\lambda_{SoC,i}$, $\lambda_{SoC,\chi}$ respectively. It is optional to take RSS into account. User profile for NRT traffic user is described as follows:

For the traffic status user profile, we use the amount of remaining data to transfer. The remaining data sizes of the user μ and other users in *X* are denoted by $\tau_{LeftFS,\mu}$ and $\tau_{LeftFS,\chi}$ respectively. The remaining data size can be thought as the traffic load that the user is going to create. The traffic status profile value of NRT user, $p_{t,\mu}$ is computed by Eq. (3.24) with $\tau_{LeftFS,\mu}$ and $\tau_{LeftFS,\chi}$ replacing $\lambda_{c,i}$ and $\lambda_{c,\chi}$, respectively. The mobility user profile for NRT traffic is identical to RT traffic. For NRT traffic, the QoS of user profile is the share of capacity user will occupy in the network. This is related with the NRT traffic scheduling policy and will determine the data transfer completion time of a NRT traffic user.

3.4.1.3. Profile matching: After the user and the network profiles are generated, we calculate the distances between the user μ and the networks in *X* after juxtaposing the user profile space and the network profile space. The distance between the user μ and a network is computed by subtracting the user profile value from the network profile value. In contrast, for the static category, we favor the best fit network by giving the largest distance. A network closer to the user gets a larger distance, whereas a network farther from the user has a smaller distance value.

3.4.2. Performance evaluation: In the proposed scheme, the coexistence of RT and NRT traffic users can be easily handled by making independent decision for each user according to their traffic type. RT traffic, such as VoIP, requires throughput and delay guarantee, while NRT traffic, such as web browsing, does not require any guarantee in throughput or delay [220]. The mutual interactions between two types of traffic are captured by the admission control policy and traffic scheduling policy.

In proposed scheme we have considered 2km x 2km map with n number of network profiles present in existing network list. There can be m number of users present in wireless heterogeneous environment as shown in Figs. 3.14 & 3.15.

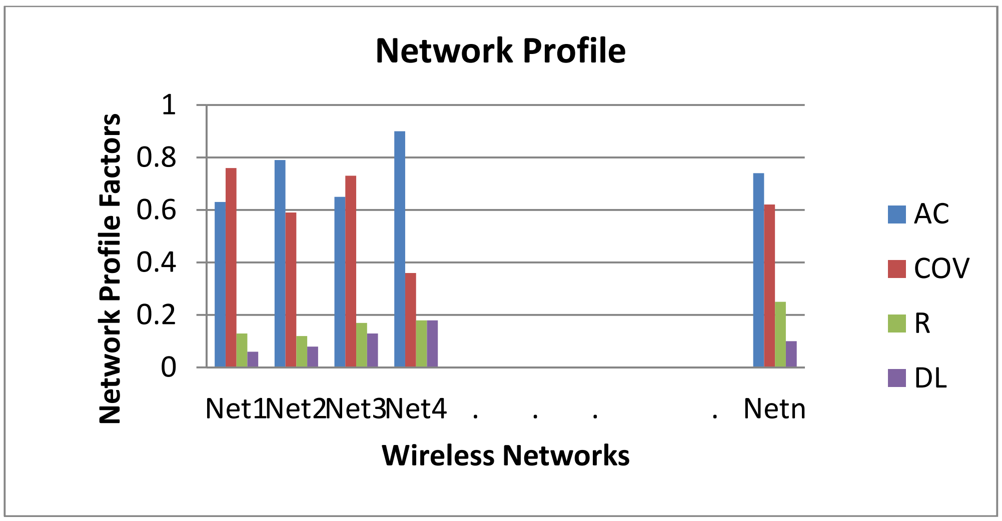


Figure 3.14: N numbers of networks with their respective profiles present in existing network list.

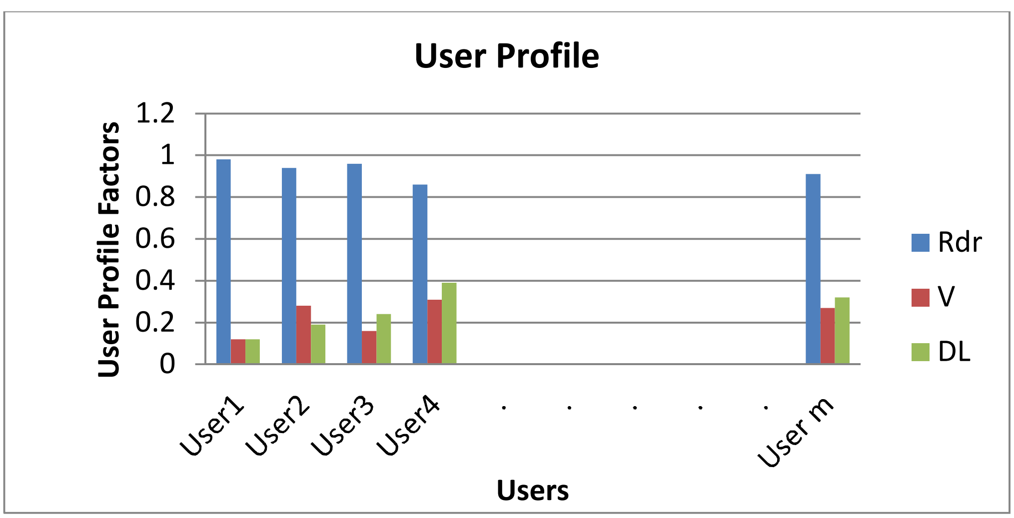


Figure 3.15: M number of users with their respective profiles present in heterogeneous wireless environment.

The random distribution mobility is used for user. The requested data rates and file sizes were distributed from 100 kbps to 300 kbps and 100 KB to 300 MB, uniformly. In MATLAB simulation of proposed algorithm n = 2 and m = 250 are considered. Network parameters are shown in Table 3.11.

Table 3.11: Network parameters in heterogeneous environment

S.No.		**Heterogeneous Wireless Networks**	
		WiMAX	**3G**
1.	**Radius**	2 Km	1 Km
2.	**Capacity**	15 Mbps	3.6 Mbps

For performance comparison, two other schemes are used: *RSS based scheme* and *hungry scheme*. In the RSS based scheme, the network with the strongest RSS is chosen. In the hungry scheme, the network with largest available capacity (RT) or average service data rate (NRT) is chosen.

Figure 3.16: Network selection frequency for multiservice and multiuser (250)

The multi service case has same number of RT and NRT users. In Fig. 3.16, the network selection triggering frequencies are compared for 250 RT and NRT users. The performance results for RT users and NRT users are depicted in Figs. 3.17 & 3.18 respectively. Regardless of network load level, the proposed scheme consistently shows the best performance among three schemes under consideration. For NRT and RT users, the performance gain of the proposed scheme is significantly expanded.

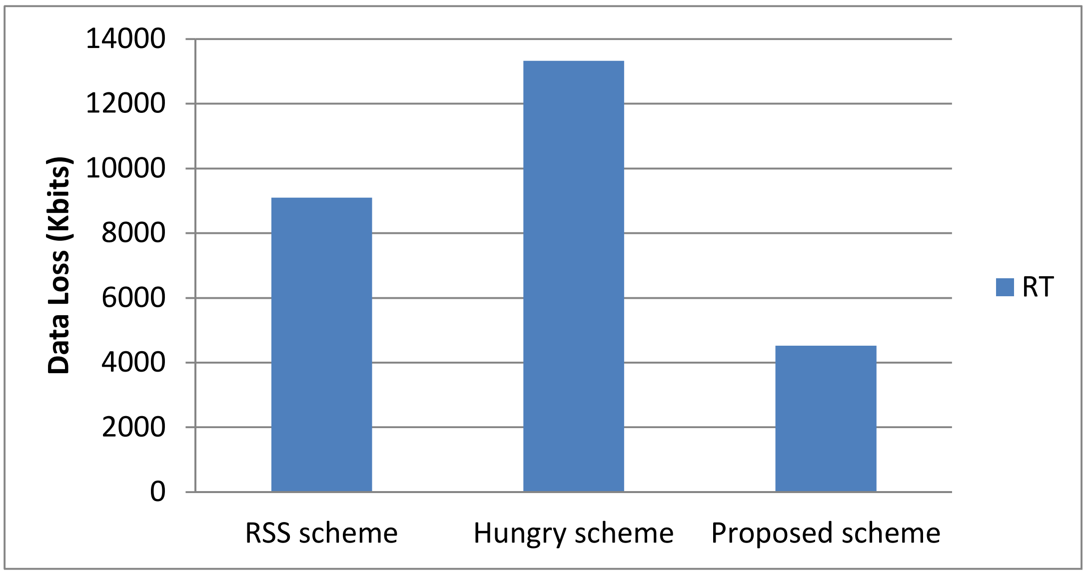


Figure 3.17: Total data loss of RT traffic users (250)

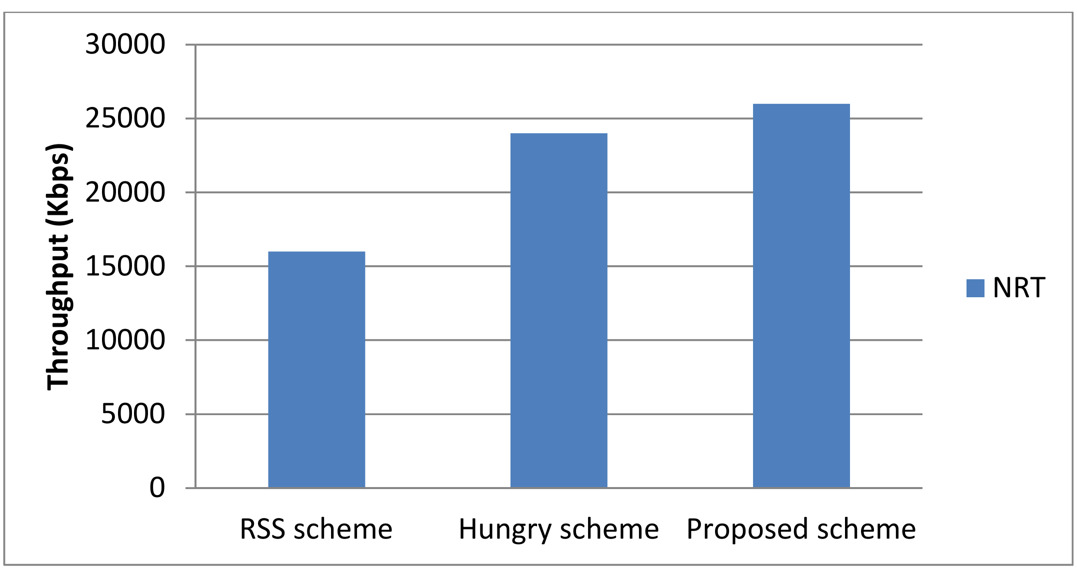


Figure 3.18: Total throughput of NRT traffic users (250)

In the RT traffic case as depicted in Fig 3.17, the proposed scheme outperforms the other three schemes by at least 10% in terms of the data loss, caused by network selection delays and overloaded networks. In NRT traffic case, the performance impact by the frequent network selection is less critical than it was in RT traffic case. The data dropped during the network selection will be retransmitted, and the better throughput of the new network can compensate the delay. Hence, the performance gains of system-wide throughput against the other schemes are better in NRT traffic as shown in Fig 3.18. Hungry scheme performs poorly in the multi service networks, particularly under heavy traffic condition. The proposed scheme improves performance by reducing the data loss and enhancing the throughput.

3.5. Summary

TOPSIS- an MCDM technique based on AHP for enabling a user being always best connected with regards to a set of criteria reflecting the needs of a generic service is implemented. Here, streaming is considered as a generic service. It is observed that network WiMAX network has the highest Preference Value (P = 0.9565) and selected the best among all available networks in heterogeneous environment. It is found that different criteria for different generic services and conditions can make a difference regarding the decision based on performance, cost and accessibility ratings. The main constraint of the study is the choice of weights of attributes of various networks. In order to resolve this issue a new network selection algorithm based on weight estimation of the representative set of the network attributes is proposed using entropy and TOPSIS approach. The proposed model is efficiently implemented to select the desired network in a heterogeneous environment of UMTS, WLAN, GPRS, and WiMAX employing triple-play services (Voice, Data and Video). The obtained numerical results show that the proposed algorithm can select the best available network in heterogeneous environments based on user preferences and/or service requirements. For voice service, the user's preference lies in minimum delay. Weight coefficient $W_1 = 0.745$ is determined for this parameter through weight assignment. GPRS is an optimal network based on BW, L and CB, even though the delay in the case of UMTS is marginally low. In the case of video service, bandwidth is the dominant parameter. $W_2 = 0.689$ is determined by the threshold video bandwidth based on the service demands. In addition, the bandwidth delay parameter ($W_1 = 0.218$) is also proved to be important for this application. Packet loss (W_3 = 0.048) and cost (W_4 = 0.045) are of less significance. Based on bandwidth, WiMAX has emerged as an optimal access network for video services. The user demands for data services at lower data cost and thus, the weight coefficient W_4 = 0.43 is set in combination with the service demand for this parameter. It can be concluded from the results that WLAN has the lowest data transfer cost. However, UMTS is declared as the optimal network because it provides better QoS, i.e., low delay and packet loss. On altering the attribute values of delay by 10% for voice users and 30% for video and data users, change in network selection occurs significantly.

In addition to above, a novel method is proposed that take into consideration user preferences (requested data rate, velocity, tolerable data loss), network conditions (available capacity, coverage, expected data loss due to network overloading/network selection delay) and QoS (network selection rate, RSS, delay, jitter) in order to select the optimal network between WiMAX and 3G and achieves the best balance between user and network performance for different real time and non-real time applications. In the RT traffic (such as VoIP) case, the proposed scheme performs better as compared to other two schemes (RSS based scheme, Hungry scheme) by at least 10% in terms of the data loss caused by network selection delays and overloaded networks. In NRT traffic (such as web browsing) case, the performance impact by the frequent network selection is less critical than in RT traffic case. The performance of system in terms of throughput against the other network selection schemes is better in NRT traffic. It yields better performance by reducing the data loss and enhancing the throughput while considering 250 users. It offers practical approach due to its simplicity and flexible structure. It finds effective equilibrium between the user's preferences, services requirements and networks conditions.

CHAPTER 4

NETWORK SELECTION BASED ON ESTIMATED AVAILABLE BANDWIDTH

4.1. Introduction

One of the design goals of a wireless network is to provide the user with the best available QoS at any time. One of the main challenges is to obtain dynamic QoS parameters such as available bandwidth. We consider available bandwidth as a dynamic parameter to select the network in heterogeneous environment. In this chapter we propose novel network selection algorithms capable of adapting to prevailing network conditions in heterogeneous environment of 3G & WLAN networks, 3G & WiMAX and WLAN & WiMAX. We utilize a bootstrap approximation based technique to estimate available bandwidth and compare it with hidden Markov model based estimation to verify its precision. It is implemented for the selection of the best suitable network in the heterogeneous environment consisting of 2G & 3G and 2G, 3G & WLAN standards based wireless networks. It is implemented in temporal and spatial domains to check its robustness. Estimation error, overhead, estimation time with varying size of traffic and reliability are used as the performance metrics. Analysis of heterogeneous system reveals that the proposed network selection methods can effectively choose the suitable network by negotiating trade-offs among network dynamic conditions and multimedia services.

4.2. A criterion for network selection in 3G and WLAN heterogeneous environment

IEEE 802.11 wireless LANs (WLANs) and 3G networks, are preferred choice in providing wireless services. WLANs and the 3G networks have complimentary characteristics. WLANs have been rapidly gaining popularity to provide high speed wireless access for indoor networks, enterprise networks, and public hotspots. Public hotspots include airports, coffee houses, hotels, convention centers, libraries and school campuses which have a high demand for wireless data services [221]. The IEEE 802.11 WLANs' success is partially due to low price of WLAN cards and high data rates. However, an IEEE 802.11 standard based network covers only a few hundred square meters with no specific mobility support. On the other hand, the 3G standards provide wide-area coverage of several kilometers in cell radius with high mobility management support, but with relatively low data rate from 64 Kbps to 2 Mbps (theoretical maxima) [221]. Although wireless cellular systems provide most of public wireless access, WLAN systems have rapidly become an important public wireless access. Furthermore, the cost of obtaining radio spectrum as well as devices for 3G networks are very expensive, whereas, WLANs use license free radio spectrum to provide higher speed wireless services. Therefore, 3G and WLAN are complementary technologies, and deployment of WLAN and 3G both together provides benefits to the end users and service providers with advantages of both technologies.

Complimentary features of WLAN and 3G provide efficient connectivity infrastructure that is not only widespread in some areas but also may have large bandwidth in some others like hot spots. Therefore, there has to be a trade off if the laptop/PDA used is required to access both networks [222]. The infrastructure is expected to be the IP based multi-service network (IP Backbone) that provides connectivity and transport via any access technology, including wireless local area networks, evolving 3rd generation systems (3G). A multi access infrastructure supports services and users having a wide variety of multi access capable (multi-mode) terminals i.e. WLAN and 3G network interfaces [223]. Thus, from a QoS and access selection point of view, the key elements of an ABC system include the Multi Interface Terminal (MIT), the access networks, the access selector (AS) entity and the IP backbone network, as depicted in Fig. 4.1.

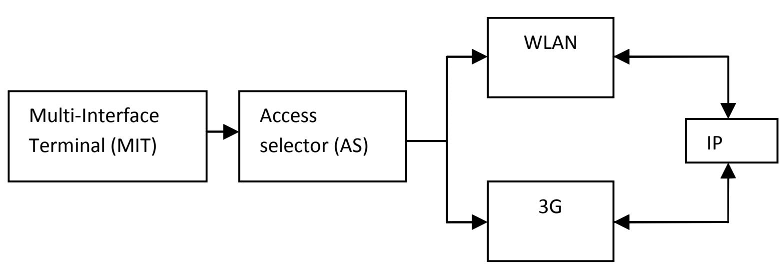


Figure 4.1: Key elements of ABC system in heterogeneous environment.

Alternatively, the access selection may be part of the network and can have direct access to important network status parameters, or it can communicate with access technology specific entities via the IP backbone network. In the access selection module, the access selection decision algorithms must be implemented to ensure that users are indeed best connected in terms of QoS, price, and possibly other preferences. Such algorithms should optimize the combined capacity of the multi-access network.

The objective is to design an access selection algorithm for the available links that must be ordered to determine the best interfaces for the most important attribute. The network ordering based on single network parameter is the simplest ordering technique but it is not the best solution. The access selection algorithm must depend on the requested services. The ordering algorithm must be able to determine automatically the best interface and the interface order that fulfills the user's requirements. The parameters provided from network that the terminal uses for making the decision of multimedia applications are available bandwidth. Available bandwidth measurement is done by using online bandwidth estimation technique based on Java script.

4.2.1. Architecture of heterogeneous environment: The wireless networks are classified in four categories depending on their coverage. These categories correspond to WPAN, WLAN, Wireless Metropolitan Area Network (WMAN) and WWAN [224]. We propose a new configuration that can be deployed for interworking two or more heterogeneous networks. Therefore, we consider that the two networks belong to two different categories, for example, the interworking of the WLAN and the 3G networks as depicted in Fig. 4.2. The networks interoperability is done to achieve different parameters such as acquiring high bandwidth, minimum interference or minimum power consumption after perfect access network selection. These parameters can be determined by the user preferences, the applications requirements or the terminal capabilities.

Most of the Wireless Internet Service Providers (WISPs) are aiming towards internetworking of the WLAN infrastructure with cellular technologies. The mobile user should be unaffected by the interchange from one network to another. In other words at a location where only a WLAN hot spot and 3G exist, the handover between WLAN and 3G should be done in a seamless manner that is only based on perfect access network selection. The infrastructure for this consists of two networks (WLAN and 3G) each of them is accessed through a proxy server. When the user of the laptop/PDA wants to access/retrieve information from the Internet, the proxy server is used to determine the type of network access. Connection from the back end of the connection that resides between the proxy server and the source/Internet is not so important. It may be a Local Area Network (LAN), Wide Area Network (WAN) or a landline connection. The intermission of the proxy server is focused on shortening download distance and time to decrease the cost.

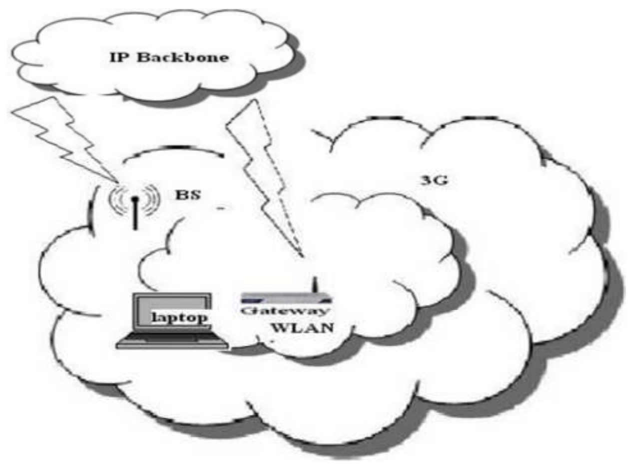


Figure 4.2: An internetworking of WLAN and 3G network

The laptop can be connected via WLAN and 3G depending upon availability of the networks. When the user is in a WLAN zone site then it can access the network either through the gateway or by default proxy server or access point (AP). The proxy server or gateway makes its connection with the internet for multimedia services required by the user. This means when WLAN is the network medium only WLAN usage will be charged. WLAN costs are lower than 3G hence; WLAN is preferred to 3G when the user steps into a WLAN site or when both are available. WLAN is a completely different network than 3G and therefore it needs to provide a different IP address to the laptop/PDA. This is also true for the case when the user moves from one segment to another segment in the WLAN environment. The IP address is changed hence the identity of the user changes with it. To the network it is all different users, because of the different IP addresses the laptop/PDA is assigned every time.

While in the case of 3G network, laptop/PDA can be connected to the Internet backbone by using the nearest base station or through proxy server of 3G network. When no downloads or web site updates are made over the 3G connection, there is also no charge for the connection itself.

As the mobile device laptop/PDA moves one place to another according to the user preference the network need to be automatically selected. In the next section available bandwidth estimation algorithm for network selection is presented.

4.2.2. Proposed network selection algorithm based on estimated available bandwidth: The flow graph in Fig. 4.3 represents the logic of access selection based on available bandwidth estimation technique for finding 'always best connected' criteria in heterogeneous environment for multimedia services. Because of multimode mobile device the user have opportunity to avail number of wireless network together. We are considering two interfaces of laptop that can access WLAN and 3G networks. The selection of network depends upon the user preference that means on the application currently running. If the application is based on multimedia services, then the foremost requirement is bandwidth. So selection of the network access depends on the network having more available bandwidth. Available bandwidth of WLAN & 3G for network selection is estimated tandemly.

First of all, we select one of the available networks then download file of specific size from that particular network interface and note the time duration. The size of the file to be downloaded should not be too large or too small. If the size of file is quite large then it takes more time and more cost which is not preferable and if the size of the file is very small then it can't accurately calculate the available bandwidth estimation. So we are considering the download file size = 96.71094 KB for testing purpose. The file is to be downloaded from the default gateway of the WLAN or 3G network. We calculate the download bandwidth by dividing download file size with time taken for downloading. The download bandwidth represents the available bandwidth of the current access interface. Select the second interface and repeat the same process as discussed above. Compare the calculated available bandwidth of both the interfaces. The interface having the highest available bandwidth is selected for the real time multimedia services.

4.2.3. Implementation of proposed algorithm: WLAN and 3G based platform is created, as shown in Fig 4.2. The platform includes default gateways, access point, base station and a number of dual mode mobile clients (laptops, cell phones or PDA's). A software platform is developed by using java for this architecture. The software architecture of dual mode client is shown in Fig. 4.4.

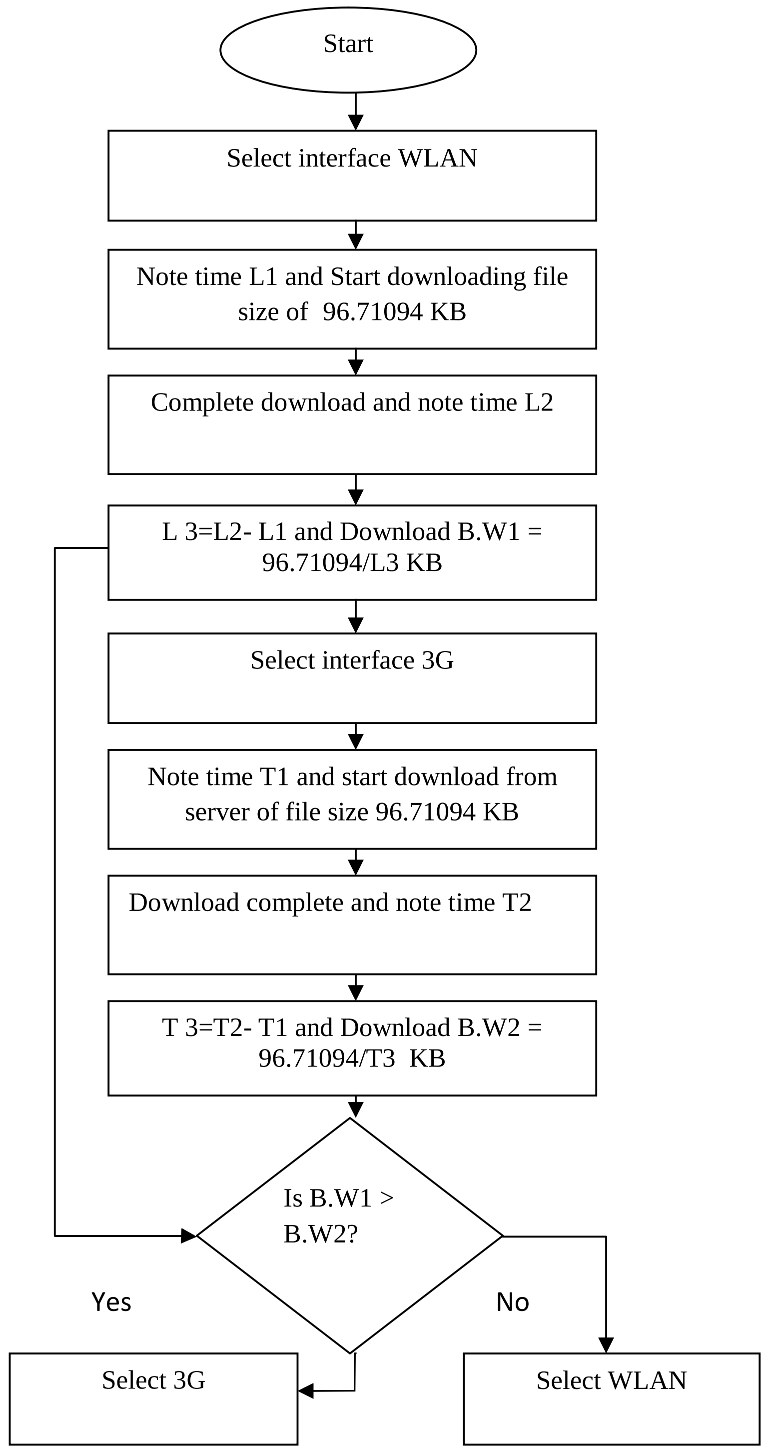


Figure 4.3: Flow chart of available bandwidth estimation algorithm for access selection in heterogeneous wireless environment

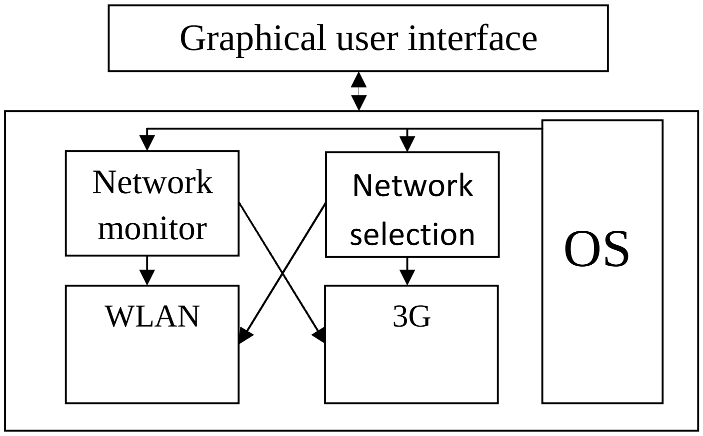


Figure 4.4: Software architecture of dual mode client.

To support seamless mobility across WLAN and 3G networks, we have developed an algorithm for mobile client to manage multiple connections using WLAN and 3G technologies. Such a client should also intelligently select and activate the ideal interface according to the network conditions.

Figure 4.5: The dual mode mobile client. [225]

However, there is no such client readily available. We developed the dual mode client. Current implementation supports 802.11b and 3G dongle as interfaces. Dual mode client software provides support for automatic roaming across WLAN/3G, which means that the client can monitor and automatically select WLAN or 3G network according to the available bandwidth estimation technique. The software system includes the following modules: a module to monitor and detect different wireless networks, a module to do network access selection decision including multiple connections management.

The proposed system was tested in the campus of DAVIET, Jalandhar by accessing Internet service through existing WLANs and the 3G networks provided by operators. Based on the integration architecture, we have a fully featured heterogeneous wireless testbed comprised of WLAN and 3G network. The software was implemented in a dual mode laptop having core 2 duo processer, T5800 @ 2.00 GHz, 3GB of RAM. The first selected interface is WLAN of dual mode laptop. The calculated download time is 10.219 seconds and the size of the download file is 96.71094 KB. The available bandwidth of WLAN interface is 75.710686 kb/sec. The second selected interface is of 3G of dual mode laptop. The calculated download time is 22.172 seconds and the size of the downloaded file is 96.71094 KB. So the available bandwidth of 3G interface is 34.8948 KB/s. Because the base station of 3G network is at more distance from the current location so it is having less signal strength than WLAN. By comparing the both network's available bandwidth, the WLAN network is selected for multimedia services as per user's preference.

All the real implementation and experimental results proves the efficiency and effectiveness of available bandwidth estimation algorithm as a practical solution for seamless communication among heterogeneous wireless networks by accurate network selection for multimedia services. In the next section, heterogeneous environment comprising of WiMAX and 3G is implemented for network selection purpose.

4.3. Real time selection in heterogeneous environment of WiMAX and 3G

The advancement of wireless communication has triggered the idea of getting connected to the internet seamlessly regardless of where we are. People are increasingly dependent on the information available on internet. Therefore, telecommunication operators are investing and bidding for more and more spectrum bands to provide services such as 3G and WiMAX to deliver broadband internet access for the users [226].

3G and WiMAX networks have a similar ability of supporting the service. It is crucial to keep the continuation and stability of application when both networks are available in heterogonous environment [145]. The problem of network selection across heterogeneous wireless networks has received much attention because of a drive for converged communication system. We also focus on network selection scheme for integrated

3G/WiMAX heterogeneous system. An application oriented dynamic network selection method has been put forth as dynamic parameter which indicates the present state of the network. Here, dynamic parameter considered is available bandwidth which refers to the maximum rate at which a new flow can transmit over a path without reducing the rate of existing flows in that path [227]. Available bandwidth estimation is extremely important for 3G & WiMAX networks, especially for applications viz. video streaming, smart phones with multiple interfaces etc. to dynamically select the best technology (WiMAX or 3G) to connect to. The most suitable network providing enough QoS guarantee is chosen as the target network, instead of the network with best performance.

4.3.1. Internetworking of WiMAX and 3G: At present, several interworking architectures between 3G and WiMAX network have been proposed in the literature. The two networks may be coupled in varying degrees of tightness, known as loosely coupled or tightly coupled [228]. In the loosely-coupled scenario, those two networks, which are at the highest level amongst their respective networks, are connected via internet. In the tightly coupled scenario, the WiMAX gateway is connected directly to the 3G gateway router and appears to the router as another internal 3G router and thus becomes a part of the 3G network. Here, we consider loosely coupled scenario for our network selection scheme in integrated 3G/WiMAX heterogeneous system. As 3G and WiMAX network have the similar ability of supporting the service, it is crucial to keep the continuation and stability of application when both networks are available simultaneously.

The internetworking of WiMAX and 3G network is shown in Fig. 4.6, wherein both the networks are connected directly to internet through their respective base stations. We are using HSDPA (High Speed Downlink Packet Access) as a 3G network. Although WiMAX and 3G (HSDPA) networks both allow high speed transfer of data over mobile networks. The standards and methods used to transmit data differ, in terms of both architecture and speed. If all users decide to download a large chunk of data from internet simultaneously, it will certainly affect the data rates. In case of HSDPA, all users will experience lower data rates, while in case of WiMAX the effect on data rates is not that significant.

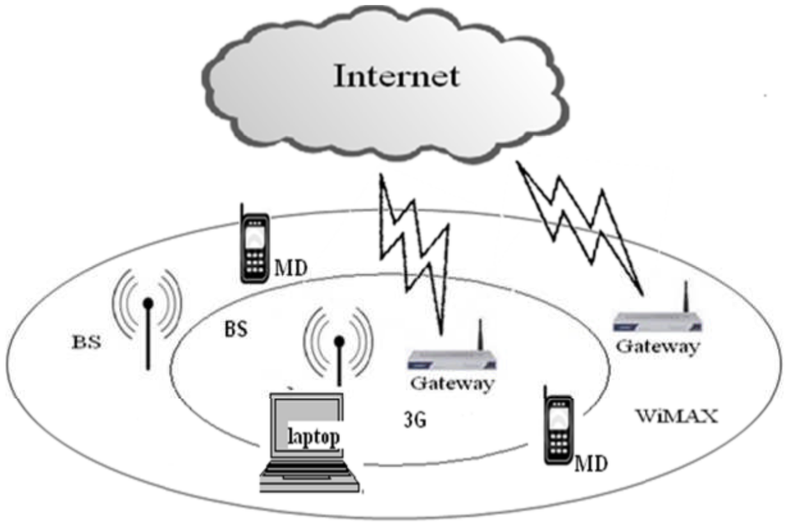


Figure 4.6: Internetworking of WiMAX and 3G network

Both technologies have practically the same capacities for transmitting multimedia data. Both WiMAX and HSDPA support QoS and traffic prioritizing, so, the choice between multimedia services in HSDPA or WiMAX is a matter of choice from the technical point of view.

As the mobile device moves from one place to another according to the network, the user preference needs to be automatically selected. In order to select the always best connected network in a given environment, we propose the available bandwidth estimation algorithm in the following section.

4.3.2. Proposed network selection based on available bandwidth estimation of WiMAX and 3G: Network performance depends on many factors. To understand the state of the network, modern operating systems support various performance observing mechanisms. However these useful features tend to drastically oversimplify the analysis of network performance. The performance of a wireless network connection depends in part on signal strength. In general, the received signal r_t at the time instant t can be expressed as [229]

$$r_t = a_t s_{t-\tau} + v_t. \tag{4.1}$$

Here, s denotes the transmitted (pilot) signal waveforms, a_t is the radio path attenuation, τ is the distance dependent delay and v_t is a noise component.

Between a computer and access point, the wireless signal strength in every direction determines the total amount of network bandwidth available along that connection. The available bandwidth (ABW) at a link refers to an unoccupied channel bandwidth. Since, at any time, a link is either idle or transmitting packets, the available bandwidth considers the average unused bandwidth over a time interval T. So,

$$A_i(t,T) = \frac{1}{T} \int_{t_0}^{T+t_0} (C_i - \lambda_i(t))dt \tag{4.2}$$

where A_i (t, T) is the available bandwidth of link i at time t, t_0 is initial time, C_i is the link's capacity, and λ_i is its traffic [230]. The available bandwidth along a path is the minimum available bandwidth of all traversed links.

The flow graph in Fig. 4.7 presents the logic of network selection based on available bandwidth estimation along with RSS technique for finding always best connected criteria in heterogeneous environment for multimedia services. Because of multimode mobile device the user have opportunity to avail number of wireless networks together.

We are considering two interfaces of laptop that access WiMAX and 3G networks. The selection of network depends upon the user preference (currently running application). If the application is based on multimedia services, then the foremost requirement is bandwidth. So selection of the network depends on the network having more available bandwidth. The available bandwidth between the available networks (3G & WiMAX) is computed in tandem.

This algorithm checks presence of networks and then disconnects all available networks. Any network from the available networks is selected its received signal strength is measured.

Then available bandwidth is estimated by downloading file of specific size from that particular network interface. The download file size of 2397 KB has been considered for testing purpose.

$$Available\ Bandwidth = Download\ file\ size / Time\ taken\ for\ downloading \tag{4.3}$$

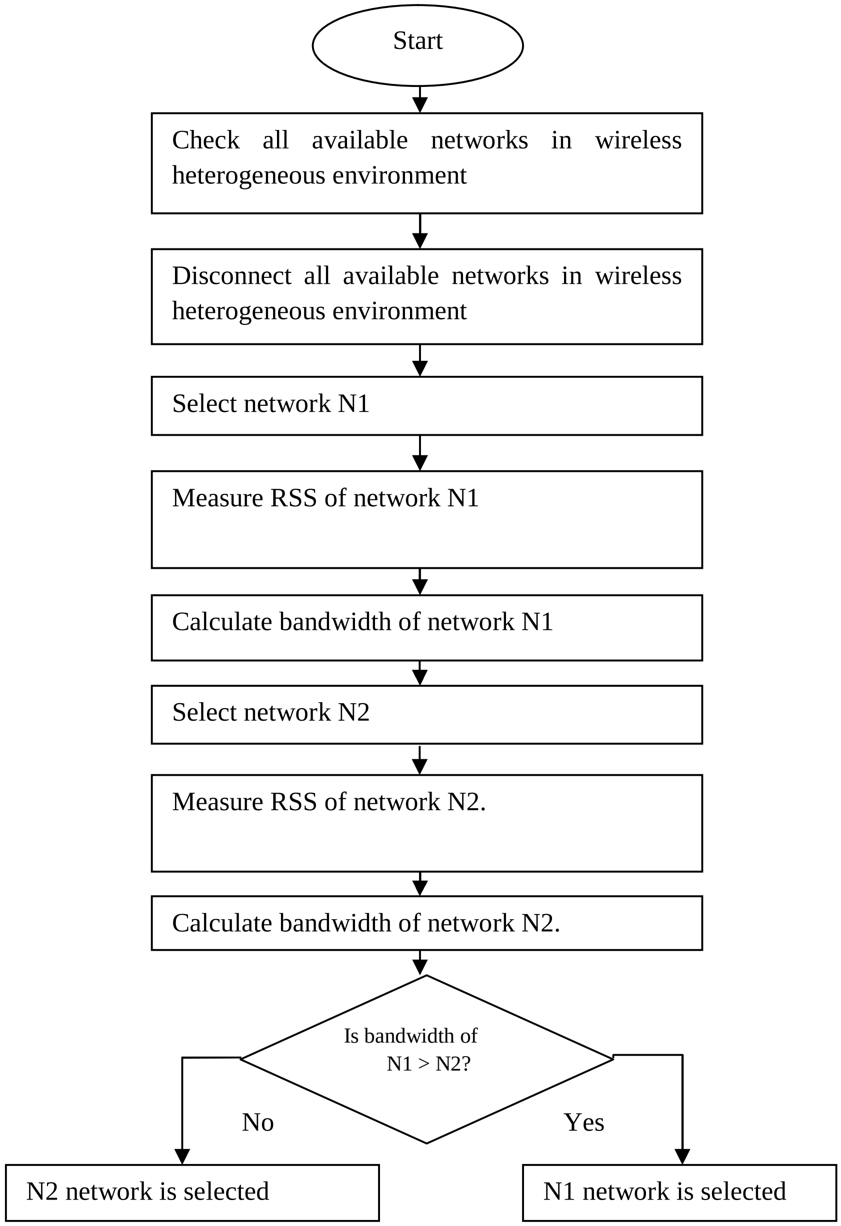


Figure 4.7: Available bandwidth estimation algorithm for network selection in heterogeneous wireless environment.

The algorithm 4.1 computes the available bandwidth of the current access interface by using Eq. 4.3. Algorithm 4.2 compares the calculated available bandwidth of both the interfaces b1 (3G) & b2 (WiMAX) respectively. Interface having the highest available bandwidth is selected for the real time multimedia services as per user preference.

Algorithm 4.1

To calculate the download speed

```
{
        speedtimer.Start()
        readBytes(4095) As Byte
        bytesread As Integer = theResponse.GetResponseStream.Read(readBytes, 0,
        4096)
        nRead += bytesread
        percent As Short = (nRead * 100) / length
        If bytesread = 0 Then Exit Do
        writeStream.Write(readBytes, 0, bytesread)
        speedtimer.Stop()
        readings += 1
        If readings >= 5 Then
        currentspeed = 20480 / (speedtimer.ElapsedMilliseconds / 1000)
        speedtimer.Reset()
        readings = 0
        End If
}
```

Algorithm 4.2

To compare and select the network

```
{
        If b1 = b2 Then
        "Use any connection both have equal bandwidth"
        ElseIf b1 > b2 Then
        "Select " connection with " bandwidth" b1
        Else
        "Select" connection with "bandwidth" b2
        End If
}
```

4.3.3. Results and discussion: We developed WiMAX (IEEE 802.16) and 3G based test bed using .net platform as shown in Fig 4.6. The architecture of dual mode client is shown in Fig 4.8. To support seamless mobility across WiMAX and 3G networks, an algorithm was developed for mobile client to manage multiple connections using WiMAX and 3G technologies. Such a client is required to intelligently select and activate the ideal interface according to the network conditions. Current implementation supports WiMAX echolife dongle and 3G dongle as interfaces and dual mode client software provides support for automatic roaming across WiMAX/3G, which means that the client can monitor and automatically select WiMAX or 3G network according to the available bandwidth estimation technique.

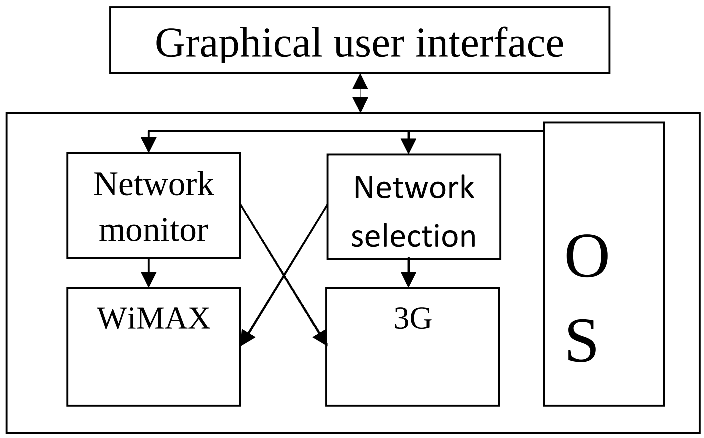


Figure 4.8: Architecture of dual mode client.

The proposed algorithm was tested for its practical functionality at Jalandhar Bharat Sanchar Nigam Ltd., the largest Telecommunications Company providing comprehensive range of telecom services in India. Based on the integration architecture, a fully featured heterogeneous wireless test bed comprised of WiMAX and 3G network is considered. In accordance with the algorithm, interface of 3G network is selected first and then WiMAX network. The estimated available bandwidth at different instances with respective received signal strength of both interfaces is tabulated in Table 4.1. It is observed that the network having more available bandwidth is automatically selected for multimedia services. The received signal strength shows the presence and current status of the network in heterogeneous environment. Also it is evident that available bandwidth is not purely depended upon RSS. High received signal strength does not ensure the high available bandwidth because it also depends upon the number of user present at that time of estimation.

By comparing the both network's available bandwidth estimation (ABE), the WiMAX/3G network is selected for multimedia services as per user's preference as shown in Fig 4.9.

Table 4.1: Estimated available bandwidth with received signal strength in heterogeneous environment of WiMAX and 3G networks.

S. No	WiMAX		3G (HSDPA)		Network Selection
	RSS (dB)	ABE (KB)	RSS (dB)	ABE (KB)	Selected networks
1.	-71.00	175.44	-75.0	5.76	WiMAX
2.	-77.83	3.66	-74.0	11.61	3G
3.	-70.58	5.97	-77.0	35.52	3G
4.	-71.07	47.06	-70.0	24.1	WiMAX

Figure 4.9: User interface for network selection algorithm based on available bandwidth estimation in heterogeneous environment of WiMAX and 3G network.

4.4. Network selection in heterogeneous environment of WLAN and WiMAX

ABC networks and services have gained much attention recently and have been adopted as one of the main drivers of 4G evolution. Collectively with the demands of high data rates and ubiquitous connectivity in 4G networks, the significance of interworking between existing and possibly new radio access technologies (RAT) are prevalent since the available resources of any single network is insufficient to meet such requirements. 4G has been envisaged as a congregation of complementary heterogeneous RATs where seamless services could be provisioned dynamically through the most efficient network based on user preferences and prevailing network conditions [157]. Further, 4G converge into an all-IP network for integrating different RATs [231]. So we consider a heterogeneous IP-based 4G architecture comprising of WLAN and WiMAX as a heterogeneous environment for network selection as illustrated in Fig. 4.10.

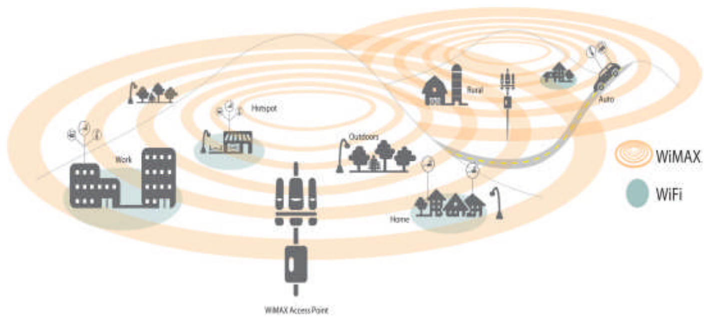


Figure 4.10: Handheld devices in mobile, portable and public hotspot environments [231]

The interworking capabilities between WiMAX and WLAN enable service providers to deliver consistent, transparent, and user-friendly broadband services to their subscribers. (See Fig. 4.11) Achieving this transparency requires two key elements: Multi-mode subscriber devices that can communicate on both WiMAX and WLAN networks and the ability to provide service across WiMAX and WLAN networks when users move between these. This is generally implemented through a controlling Access Service Network Gateway (ASN GW) and common Authentication, Authorization, and Accounting (AAA) service functionality located in the service provider network.

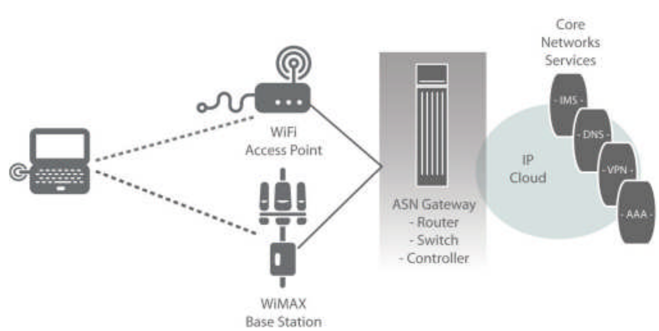


Figure 4.11: WiMAX/WLAN interworking environment [231]

The IP based core network enables easy exploitation of existing mobile IP techniques to achieve seamless handover with QoS support [232]. However, the access network heterogeneity demands an efficient network selection scheme such that users can be the best connected through multimode terminals.

In proposed algorithm the available links must be ranked to determinate the best interfaces for the most important attribute. The simplest method of ranking is to make it based on only one network parameter. However, it is not the best solution. The network selection algorithm must depend on the requested services. The ordering algorithm must be able to determine automatically the best interface and the interface order that fulfills the user's requirements. The parameter available bandwidth is provided by the network and in turn used by the terminal for making the decision on multimedia applications. Available bandwidth measurement is done by using online bandwidth estimation technique.

4.4.1. Integrated WiMAX and WLAN heterogeneous wireless network: The general WLAN/WiMAX interworking environment considered for network selection in heterogeneous wireless network by using dynamic parameter as available bandwidth estimation is illustrated in Fig 4.12. The necessary changes in both WLAN and WiMAX systems are rather limited as it will integrate both systems at the IP layer and relies on the IP protocol to handle mobility between access networks. The main characteristic of this architecture is that it considers two overlapped cells of a Mobile WiMAX and a WLAN, where both cells are served by a Base Station (BS) and an Access Point (AP) respectively. The mobile terminal has a dual interface: WiMAX and WLAN.

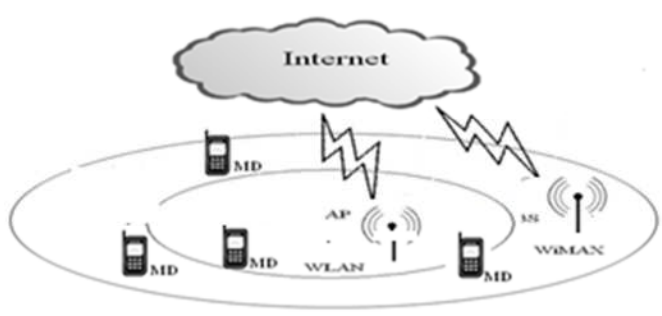


Figure 4.12: An integrated WiMAX and WLAN heterogeneous wireless network environment.

4.4.2. Network selection based on available bandwidth estimation of WLAN and WiMAX: The performance of a wireless network connection depends on signal strength and available bandwidth as described in section 4.3.2. Network selection scheme is based on these performance parameters. The flow graph in Fig 4.13 presents the logic of network selection based on available bandwidth estimation along with RSS technique for finding always best connected criteria in heterogeneous environment for multimedia services. It is assumed that laptop has two interfaces capable of accessing WLAN and WiMAX networks. Available bandwidth between the available networks (WLAN & WiMAX) is calculated individually.

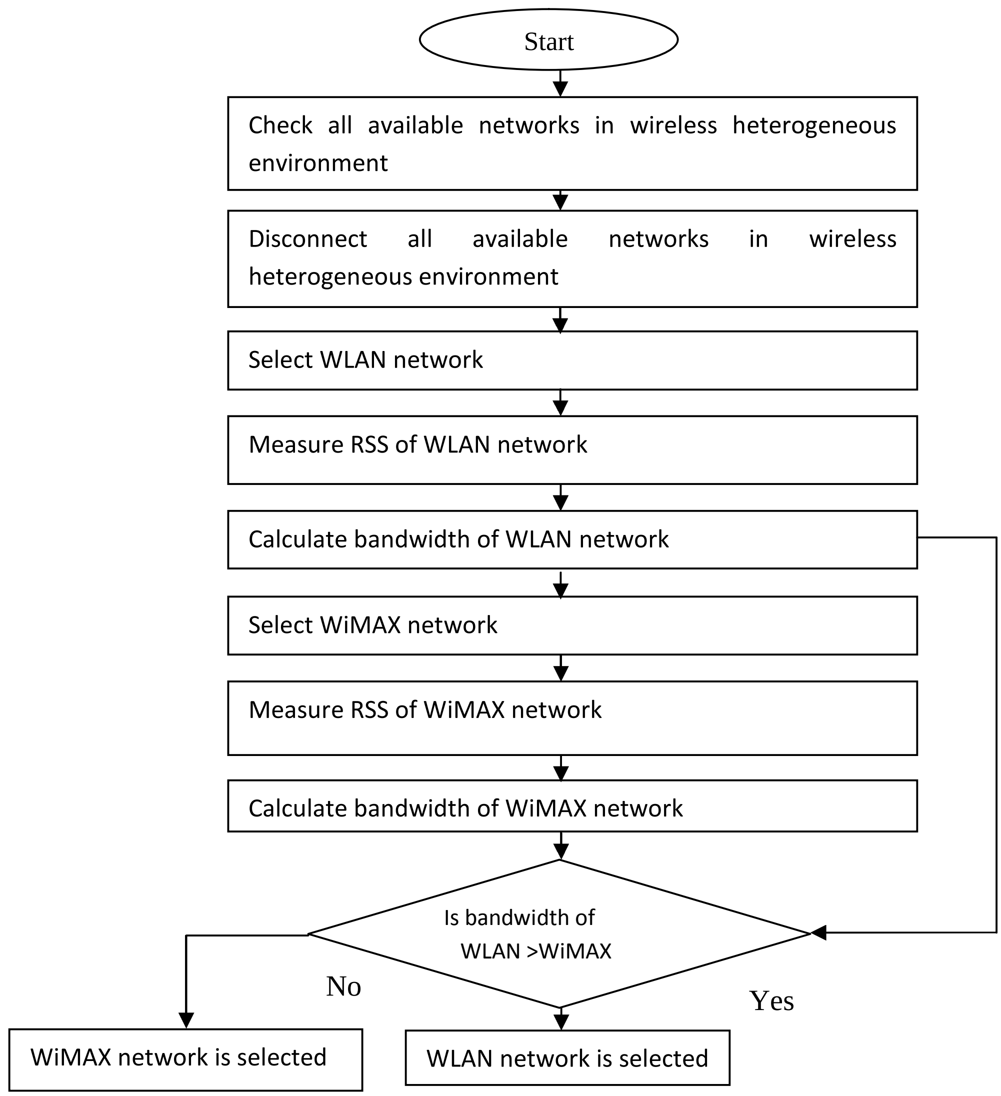


Figure 4.13: Flow chart of available bandwidth estimation algorithm for network selection in heterogeneous wireless environment.

Repeat the same process as discussed above in section 4.3.2. Then compare the calculated available bandwidth of both the interfaces i.e b1 (WLAN) and b2 (WiMAX) respectively.

The interface with high available bandwidth is selected. In the following section, the practical implementation of the proposed algorithm is described.

4.4.3. Implementation of network selection algorithm: WLAN (IEEE 802.11) and WiMAX (IEEE 802.16) based platform is configured, as shown in Fig 4.12. The platform includes access point, base station and a number of dual mode mobile clients (laptops, cell phones or palm-tops). A software platform for this architecture for network selection in this heterogeneous environment is developed by using .net. The software architecture of dual mode client is shown in Fig 4.14 as follows.

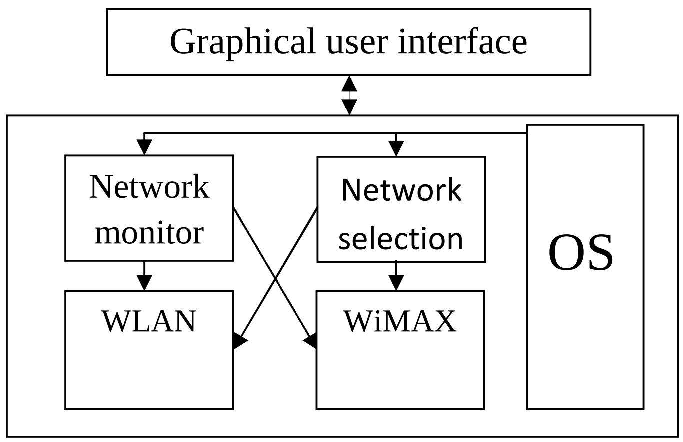


Figure 4.14: Software architecture of dual mode client**.**

To support seamless mobility across WLAN and WiMAX networks, development of mobile client software is performed to manage multiple connections using WLAN and WiMAX technologies. Such a client should also intelligently select and activate the ideal interface according to the network conditions. The dual mode client is developed as shown in Fig 4.5. Current implementation supports 802.11b/g (also known as WLAN) and WiMAX dongle as interfaces, and can easily be extended to other types of interface.

Dual mode client software provides support for automatic roaming across WLAN and WiMAX, which means that the client can monitor and automatically select WLAN or WiMAX network according to the available bandwidth estimation technique. The software system includes one module to monitor and detect different wireless networks and another module to do network selection decision.

Based on the integration architecture, a fully featured heterogeneous wireless test bed comprising of WiMAX and WLAN network and software platform is deployed in the BSNL, Jalandhar. The interface of WLAN of dual mode laptop is selected first and then WiMAX interface is selected. The estimated available bandwidth at different instances with respective received signal strength of both interfaces of dual mode laptop is shown in Table 4.2. It is observed that the network having more available bandwidth is automatically selected for multimedia services.

Table 4.2: Estimated available bandwidth with received signal strength in heterogeneous environment of WiMAX and WLAN networks.

S.No	**WLAN**		**WiMAX**		**Network Selection**
	RSS (dB)	**BW (KB)**	**RSS (dB)**	**BW (KB)**	**Selected networks**
1.	-45.0	68.03	-54.76	2.33	WLAN
2.	-40.0	77.82	-70.93	149.25	WiMAX
3.	-41.0	53.19	-54.65	155.04	WiMAX
4.	-44.0	2.34	-57.78	148.15	WiMAX

By comparing the both network's available bandwidth, the WiMAX/WLAN network is selected for multimedia services as per user's preference as shown in Fig 4.15.

All the real implementation and experimental results proves the efficiency and effectiveness of available bandwidth estimation algorithm. In this algorithm available bandwidth is computed by taking average of measurements so that it will show more accurate estimated bandwidth rather than showing the only one instance estimated available bandwidth. It can be considered as a practical solution for seamless communication among heterogeneous wireless networks by accurate network selection for multimedia services.

4.5. Available link bandwidth based network selection in Multi-access Networks

The existing deployment of wireless technologies contains both 2G and 3G standards. Network selection in such heterogeneous environment is an important research problem. We aim to implement an available link bandwidth based network selection algorithm on this environment.

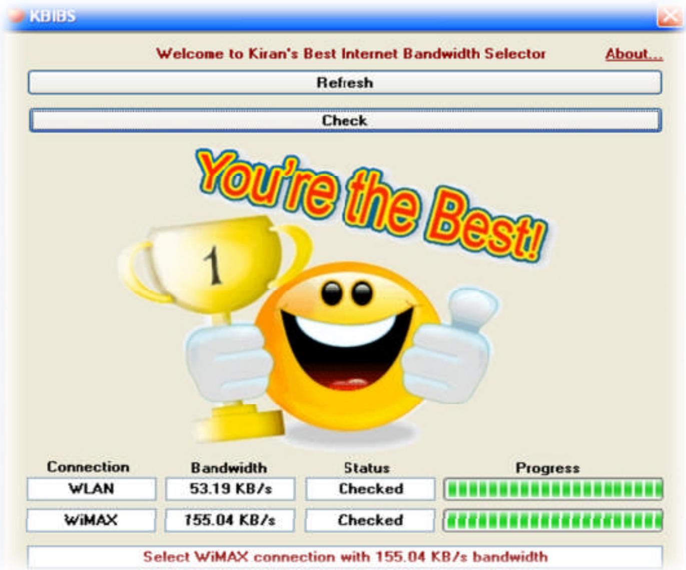


Figure 4.15: User interface for network selection algorithm based on available bandwidth estimation in heterogeneous environment of WiMAX and WLAN network.

Available bandwidth estimation is derived through bootstrap approximation method, which is then applied to select the appropriate network in heterogeneous environment consisting of 2G and 3G standards in this section. 2G standard, for example, GSM and 3G standard-HSDPA (High Speed Downlink Packet Access) wireless technologies typically provide data access rate which may vary from 9.6 Kbps through 2 Mbps for 3G [233]. These rates are generally adequate for services employing a low to medium bandwidth e.g. text messaging, voice communications, electronic mail, instant messaging with no or relatively small attachments etc. Both 2G and 3G are merely milestones in mobile technology and represent two different phases. 3G mobile networks have new set of communication protocols due to rapid increase in data services and development in hardware and software. It makes available many more features for mobile users such as internet, mobile TV, video conferencing, video calls, mobile gaming whereas there are no such features in 2G [49]. There is only voice transmit in 2G, whereas, 3G permits data transfer besides transmission of voice. The precision of voice in 3G is considerably more than 2G, and there are very slight disturbances. It is a much more safe technology than 2G. As the commercial companies compete with each other to increase their market potential, so to save 2G customers and to bring a new 3G customers, it is ensured that the subscriber can move seamlessly from one cell to another cell covered by different networks, without being aware of underlying technology [234]. An effective and efficient network selection scheme based on available link bandwidth estimation by using bootstrap approximation method based on the real time network state is proposed. It allows mobile terminals to select the most appropriate network dynamically between 2G/3G as per requisition of the user. 2G and 3G networks both have similar properties to transfer of data over mobile networks but differ in terms of speed and architecture. So, the choice between 2G or 3G networks have significant role for multimedia services.

4.5.1 Proposed network selection algorithm: A network selection scheme is proposed in order to select the always best connected network in a given heterogeneous environment. The flow graph in Fig. 4.16 presents stepwise selection process of always best connected network in heterogeneous environment for multimedia services. The logic of network selection is based on available bandwidth estimation with bootstrap approximation method and RSS technique. Number of available wireless networks is possible because the user have multimode mobile device which can access 2G and 3G networks. The selection of access network depends upon the user inclination that means on the application presently running. For multimedia services the foremost requirement is bandwidth. Access network selection depends on the network having more available bandwidth.

Step 1: Make sure the existence of networks and then disengage all available networks. Choose one of the available networks and quantify its received signal strength as described in section 4.3.2.

Step 2: Available bandwidth (ABW) is considered as dynamic parameter for network selection in heterogeneous environment as described in section 4.3.2.

Available Bandwidth in general, is non-stationary QoS information of wireless network. But when it is observed over a short time, it may be considered as stationary. In proposed algorithm, bootstrap approximation is employed to estimate available bandwidth by calculating the short-term stationary component.

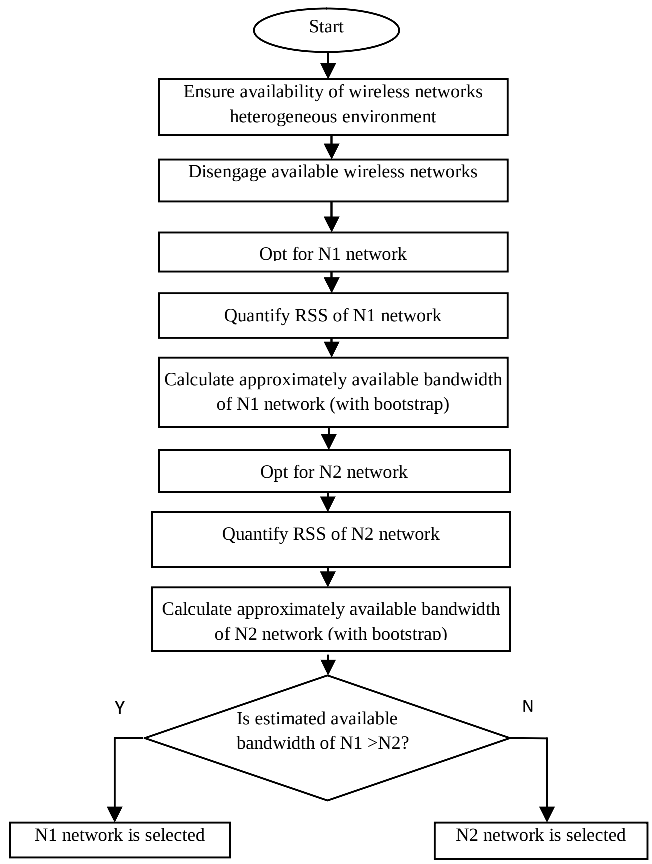


Figure 4.16: Available bandwidth estimation algorithm for network selection heterogeneous wireless environment.

4.5.1.1. Bootstrap approximation method for available bandwidth estimation: Bootstrap approximation method for available bandwidth estimation: 2G/3G network's average available bandwidth is denoted by θ from a population with distribution function (F), and then measured 2G/3G available bandwidth. It is approximated during data acquisition window. Bootstrap method is considered to draw random samples x_i from an unknown distribution function (F) to form the new data set based on original data:

$$X = (x_1, x_2, \ldots\ldots\ldots.., x_n) \tag{4.4}$$

An original data set provides a simple estimate of the entire population known as the discrete empirical distribution (F_e). Each x has probability mass of $1/n$, which has an equal likelihood of being chosen when re-sampling from F_e. The bootstrap data set is then defined to be a random sample of size n drawn with replacement from F_e. Since we want to estimate the parameter θ_e by calculating a statistic from a random sample, correspondingly, we can calculate the same statistic from a bootstrap data set:

$$X^* = (x_1^*, x_2^*, x_3^*, \ldots\ldots, x_n^*) \tag{4.5}$$

for bootstrap replication of θ_e , Eq. (4.6) is considered:

$$\theta^*_b = s(X^*_b), b = 1, 2, 3, \ldots\ldots\ldots, B \tag{4.6}$$

Where X^*_b is equal to the b_{th} bootstrap data set of B independent bootstrap data sets. The statistic of interest (X) is the sample median $\tilde{x}$ then $s\ (X^*)$ is the median of the bootstrap data set $\tilde{x}^*$. Hence, B bootstrap replicates give an estimate of the θ_e distribution, which is the bootstrap estimate of the 2G/3G average available bandwidth distribution, and its standard deviation is the bootstrap estimate of standard error for θ_e given in [235].

$$SE_b\ (\theta_e) = \sqrt{\frac{1}{B-1}} \sum_{b=1}^{B} (\theta_b^* \ - \theta^*)\ ,\ \theta^* = \frac{1}{B} \sum_{b=1}^{B} \theta_b^* \tag{4.7}$$

When sampling is done with replacement, then it is possible that some x_i would occur more than once or not at all. It can be mitigated with the smooth bootstrap technique where bootstrap data sets are constructed from a smooth empirical distribution $\hat{}\ Fs$. The available bandwidth of the 2G and 3G access interfaces is computed by using Eq. (4.4 - 4.7).

Step 3: Estimated available bandwidth is compared with Hidden Markov Model (HMM) based estimation to check the precision. The HMM consists of five elements i.e. Number of states (N), Number of distinct observation symbols per state (M), State transition probability matrix (A), Observation probabilities (B) and Initial state probabilities (Π) defined in [112]. Probabilities are denoted as (A, B, Π) to show the complete parameter set of model λ. The set of samples are taken from the network during time period (T) as observations are denoted as O. The model is used to underpin the most likely sequence of states that generated λ = (A, B, Π) for which the P(O/ λ) is maximized using the Viterbi algorithm [236]. From a particular state the most likely path is selected to all possible paths according to the above said algorithm and it does the same for each state. The most likely path that sampling packets have observed during the sampling time depicts the levels of ABW. As defined in Eq. 4.2, the final estimation is based on the average utilization observed during T. A final ABW estimation is calculated as the average state in the sequence multiplied by the link capacity.

Step 4: Compare available bandwidth of both the interfaces b1 (2G) & b2 (3G) calculated with bootstrap approximation. Network having the highest available bandwidth is selected as access network for the real time multimedia application.

System under deliberation for employing proposed network selection scheme is described in following section.

4.5.2. Experimental setup for implementation of proposed algorithm: We consider a heterogeneous environment consisting of GSM (2G) and HSDPA (3G) networks for network configuration as shown in Fig. 4.17. In the present configuration, we consider loosely-coupled scenario. As 2G and 3G network have the comparable ability of supporting the service, it is decisive to keep the continuation and stability of application, when both networks are available simultaneously.

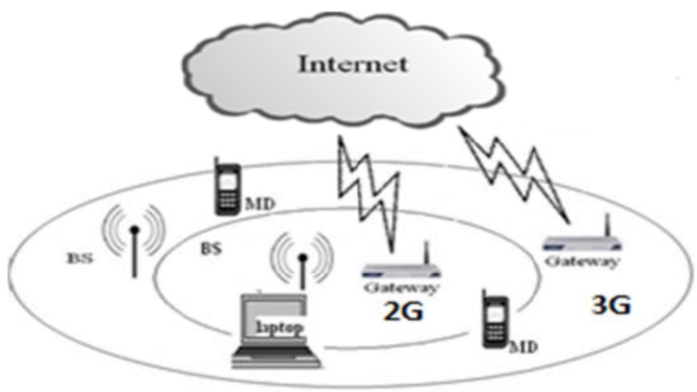


Figure 4.17: Heterogeneous wireless network model

2G and 3G network based test bed is developed using dongles and .net platform as shown in Fig 4.16 for practical implementation of proposed algorithm. It includes base stations and a multimode mobile client like laptops, cell phones or PDAs. A hardware and software architecture module of dual mode client is shown in Fig 4.18. Hardware implementation of proposed algorithm is supported by 2G and 3G dongle by huwaeii as interfaces for wireless networks. The software system consists of modules to monitor, detect different wireless networks and network access selection decision.

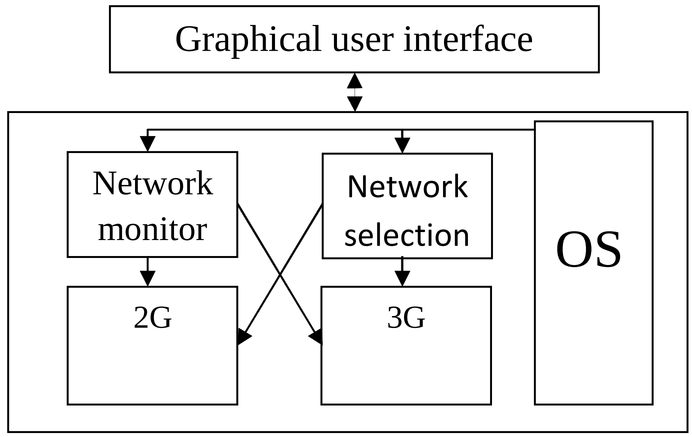


Figure 4.18: Software module of dual mode client

Dual mode client hardware and software modules provide support for automatic roaming across 2G and 3G network. The client can monitor and automatically select 2G or 3G network according to the available bandwidth estimation technique. In accordance with the algorithm, interface of 2G was selected first and then 3G.

4.5.3. Results and discussion: Bootstrap approximation is a potential method for estimating available link bandwidth in wireless networks for network selection in wireless heterogeneous environment. For obtaining numerical results, we have performed the operation every second with sample size $n = 5$ and number of bootstrap replications $B = 10$. The number of bootstrap samples may be increased in accordance with the computing power available with the node. Increasing the number of samples can reduce the effects of random sampling errors.

To check the precision of bootstrap approximation based estimated available bandwidth hidden markov estimation model applied. The number of possible states (N) and number of distinct observation symbols (M) in the HMM estimation are considered equal to 5. States represent available bandwidth level [(L (Low) = (0, 0.2) to (H (High) = (0.8, 1)] during time $t = 1$ to time $t = T$ in seconds. Transitions between states are determined by probabilities specified in the transition probability matrix A, where each step transition probability matrix is determined by movements between available bandwidth levels. Initially transition matrix (A_0) is generated randomly of size [5, 5]. Due to highly loaded network, it is expected that observation symbols have small values and conversely. Based on these observation symbols, probability values are assigned and fixed in the HMM model in term of B. The size of B is [5, 5] due to five states and five observation symbols. Π provides probabilities for each state to be the first in the state sequence. λ model is computed based on 70 observations. The λ model is used to determine the most likely sequence of states. For the every new estimation, initial model λ_0 is the output of the previous estimation. The sequence of states is then averaged and multiplied by the link capacity to provide a final ABW estimation. Fig 4.19 represents the comparison of real ABW, bootstrap estimated ABW and hidden markov model estimated ABW.

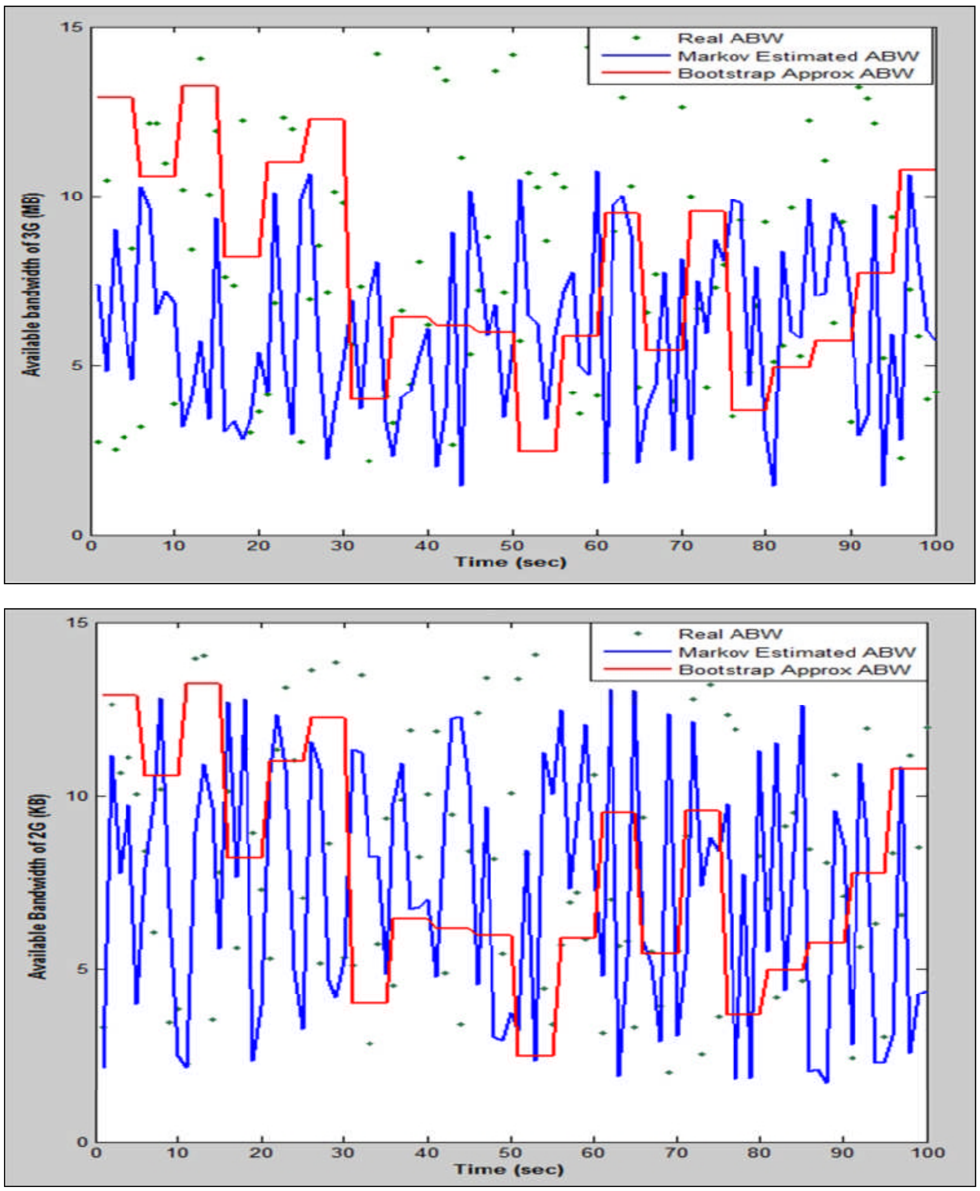


Figure 4.19: Comparison of available bandwidth estimated by bootstrap approximation method and Hidden Markov model for 2G and 3G network in heterogeneous environment

The estimated available bandwidth at different instances with respective RSS of both interfaces is tabulated in Table 4.3. It is observed that the network with more available bandwidth is automatically selected for real time multimedia services. RSS is measured to see the presence various wireless network in region and contemporary status of the network in heterogeneous environment. It is also observed that available bandwidth is not exactly dependent upon RSS. If RSS is large in value at any instance then it does not ensure that the respective network have high available bandwidth. Number of users access respective network at the instance of bandwidth estimation also prominently affected its value.

Table 4.3: Estimated available bandwidth with received signal strength in heterogeneous environment of 2G and 3G networks is tabulated

S. No	**2G (GSM)**		**3G (HSDPA)**		**Network Selection**
	RSS (dBm)	**ABE (KB)**	**RSS (dBm)**	**ABE (KB)**	**Selected network**
1.	-76.0	10.79	-75.0	9.83	**2G**
2.	-74.0	12.12	-77.0	32.02	**3G**

Figure 4.20: User interface of network selection algorithm based on available bandwidth estimation in heterogeneous environment of 2G and 3G network.

The 2G/3G network is selected for multimedia services as per user's inclination when comparing their available bandwidth based on bootstrap approximation, as shown in Fig 4.20.

4.5.3.1. Performance evaluation of proposed algorithm for network selection: For performance estimation of the proposed algorithm following scenarios have been considered.

Case 1: In this case proposed algorithm is tested at different times and locations. It is observed from Fig. 4.21 (a) & (b) that available bandwidth values estimated at different times and locations are different because at any time or location the number of users share the wireless network is dynamic which leads to variation of the bandwidth available to a user. At any instance or location 2G/3G can be selected depending upon their current status of ABW. It is measured in KB.

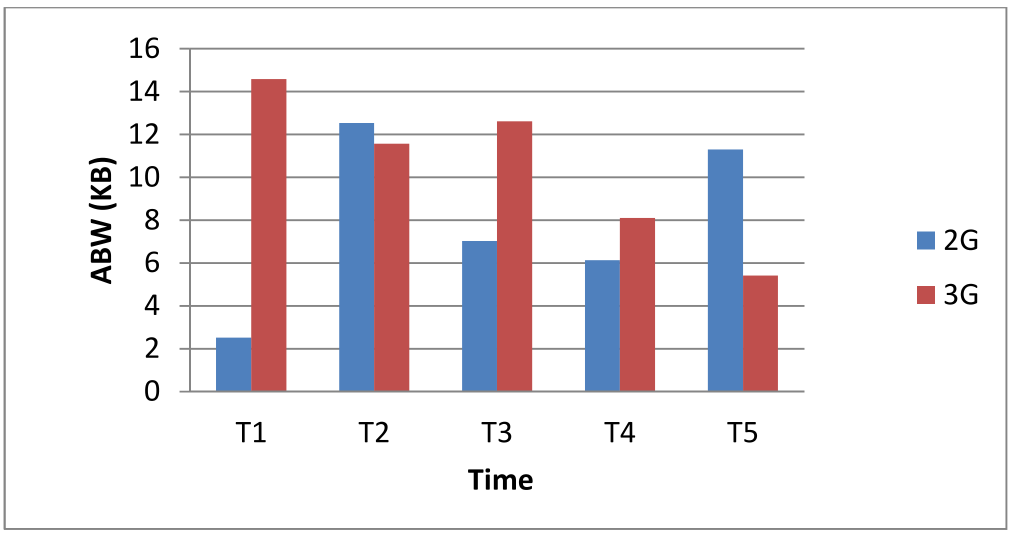


Figure 4.21: (a) Available bandwidth vs. Time

Case 2: In this case impact of downloading file size for bootstrap approximation to measure ABW is evaluated. The selection of size of file to be downloaded for estimation of real time available bandwidth by using bootstrap approximation is critical issue. Choice of size of file to be downloaded depends upon the cost and time consumption bear by the active user. From Fig 4.21 (c) it is clear that if file size is too small such as 9KB then estimation of ABW is not feasible or proper, but as the file size increases it starts working properly.

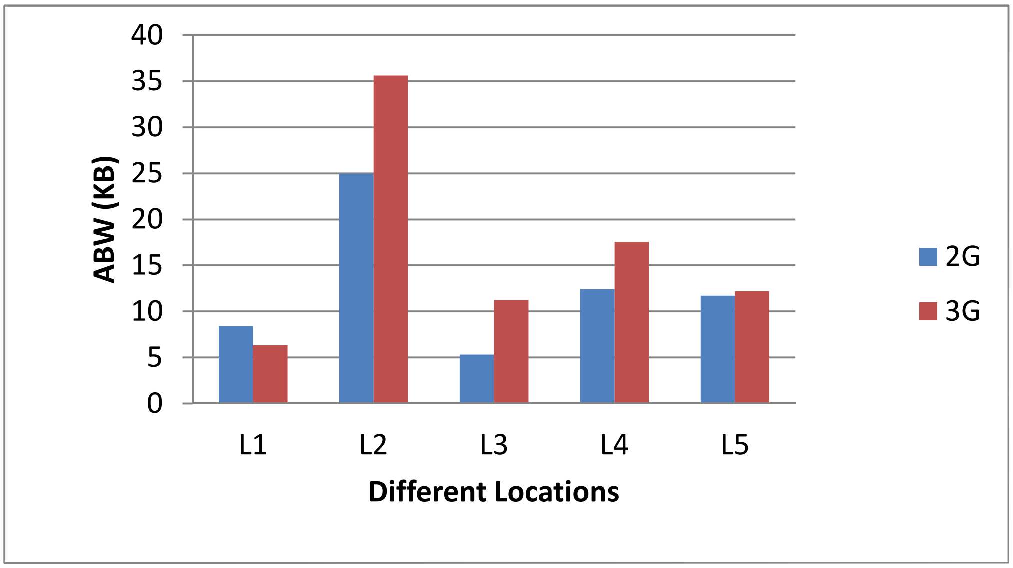


Figure 4.21: (b) Available bandwidth vs. different locations

In Fig 4.21 (d) as the file size increases the estimation time is also increases respectively in both wireless networks available in heterogeneous environment. 2G/3G network's ABW estimation time can be changed because at any instance the number of user in any of the wireless network is random. When any of the networks in heterogeneous environment uses a large chunk of its available bandwidth for downloading a file, speed of the network is compromised and estimation time increases in same proportion.

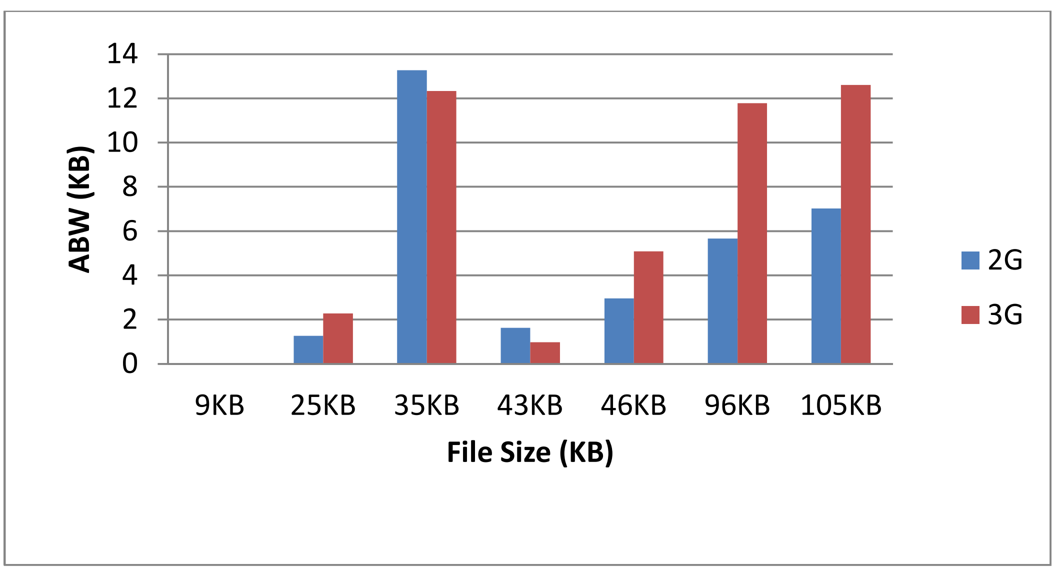


Figure 4.21: (c) File size vs. ABW

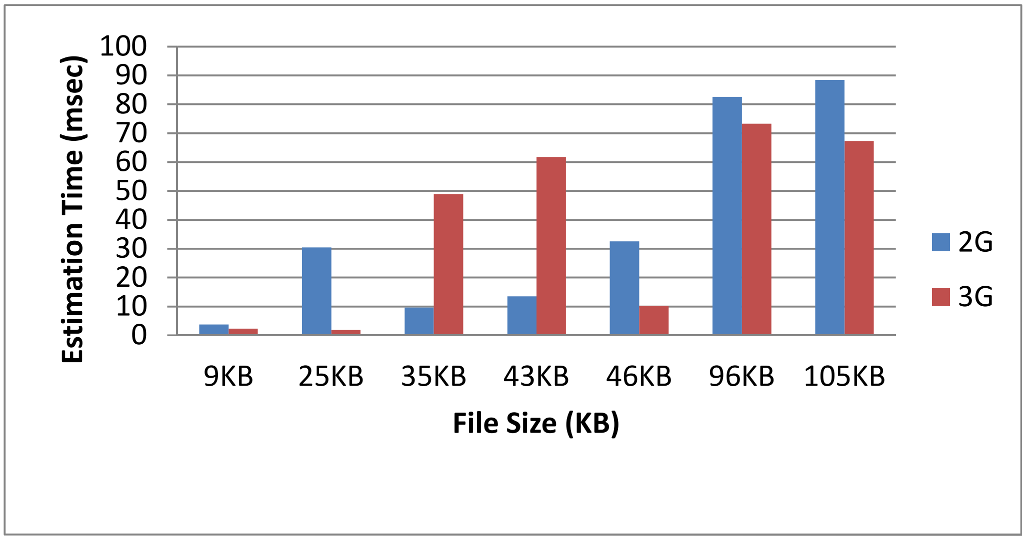


Figure 4.21: (d) File size vs. ABW estimation time

The performance of proposed algorithm is based on the quality ABW estimation. ABW estimation always faces the challenge of correctly determining the actual value of the metric. It is challenging in wireless networks, since the capacity of wireless links is affected by link layer mechanisms such as rate adaptation or ARQ, and the available bandwidth or achievable throughput over a given link is affected not only by cross traffic over that link but also by the presence of other clients.

The efficiency of ABW estimation is evaluated on the basis of metrics: estimation error, overhead and reliability to check the robustness of the proposed algorithm for network selection in heterogeneous environment of 2G and 3G.

The estimation error (or relative error) metric provides a quantitative value to measure accuracy of ABW [230]. It is measured in two phases. In first phase M_1 is ABW estimated by proposed algorithm. Then Γ is induced change in traffic or file size whose rate is given by $\Gamma = 0.5 \times M_1$. Again proposed algorithm is applied to estimate ABW denoted as M_2.

$$\text{Estimation error (or relative error \%)} = \frac{\Gamma-(M1-M2)}{\Gamma} \tag{4.8}$$

Assuming that the traffic of other users does not change much between the two phases, the actual change in available bandwidth is given as Γ. To mitigate the impact of changing network conditions on results, the two phases conducted very close to each other. Check for consistency, repeat the same experiment multiple times over the same link. By using Eq. (4.8), proposed algorithm's ABW estimation error is calculated. It varies usually less than 18% in all networks present in heterogeneous environment (i.e. 2G, 3G) except the case where the error can be as high as 100% due to congested link (in peak hours). It is observed that estimation error is less in proposed algorithm in comparison of existing ABW estimation techniques in [237].

Overhead metric is defined as the percentage of traffic (file to be downloaded) respect to the capacity of the link.

$$\text{Overhead (\%)} = \frac{File\ Size}{Link\ Capcity} \times 100 \qquad (4.9)$$

In proposed algorithm, file size (or traffic) varies from 9 KB to 105 KB and link capacity is considered 9.6 Kbps and 2 Mbps for 2G and 3G network respectively. Overhead is calculated by using Eq. (4.9). It is 6.25% to 72.91% in case of 2G and 0.45% to 5.25% in case of 3G network of heterogeneous environment. In comparison with existing techniques [237], there is less overhead in proposed algorithm's ABW estimation. Third evaluation metric is the estimation time which indicates that how long the proposed algorithm' ABW takes to provide the estimation. It is usually expressed in seconds. It varies from 2.348 msec to 88.485 msec in proposed algorithm by using file size (or traffic) varying from 9KB to 105KB. It is in the range of milliseconds in case of proposed algorithm ABW estimation in comparison of existing tool described in [237].

Reliability provides information about the robustness of the algorithm. The reliability is specified by the percentage of tests the algorithm succeeded to provide an ABW estimate. It is calculated by dividing the number of replications for a particular experiment with the final number of trials needed to perform to reach that number. Thus, a 100% reliable algorithm needed N trials to provide N_0 estimations.

$$\text{Reliability (\%)} = \frac{Number\ of\ estimations}{Number\ of\ trials} \times 100 \qquad (4.10)$$

Reliability is measured by N = 100 (number of trails) and N_0 = 99 (number of estimations) by using Eq. (4.10). Proposed algorithm is 99% reliable and robust than existing ABW techniques discussed in [237]. 1% unreliability in ABW estimation creeps in if the file to be downloaded doesn't exist or remote server doesn't respond.

It surfaces from the above analysis that the proposed algorithm's ABW estimation is more efficient in comparison to that reported in [237] on the basis of relative accuracy (estimation error), overhead, estimation time and reliability which further validates the feasibility of proposed algorithm for network selection in heterogeneous environment of 2G and 3G .The results of the said algorithm are better in term of estimation time with the findings reported in [238], which further justify the validity of this algorithm.

4.6. Dynamic network selection in heterogeneous environment of 2G, 3G and WLAN networks

When network conditions vary, the applications may select better network transparently. Users have a wide variety of multi-access capable multi-interface terminals (MIT). Such multi-access infrastructure supports multimedia services [239-240]. In this section, three access networks 2G, 3G and WLAN are considered in wireless heterogeneous environment for selection by using the proposed dynamic access selection algorithm based on available bandwidth estimation by using bootstrap approximation method. Multi service network (IP Backbone) provides connectivity and transport via access technology, (e.g. 2G, 3G and WLAN) as shown in Fig. 4.22. The access selection decision algorithm is implemented in AS module to ensure that users are indeed best connected in terms of QoS and possibly other preferences. Decision algorithm optimizes the combined capacity of the multi access network infrastructure. The AS may be part of the network and can have direct access to important network status parameters, or it can communicate with access technology specific entities via the IP backbone network.

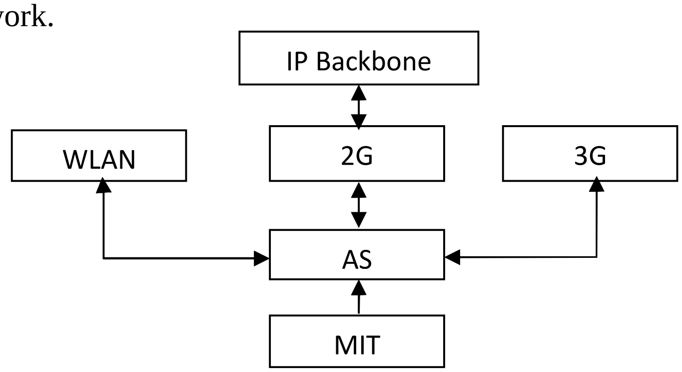


Figure 4.22: Key elements of ABC system in heterogeneous environment.

Users need to know currently which available radio access network is most suitable for their services and transfer requirements. The AS module selects the radio access network that best suits the user needs while taking into consideration its effect on performance of overall network.

4.6.1. Architecture of heterogeneous environment: A heterogeneous communication network provides transparent, self-configurable WLAN (e.g., IEEE 802.11a/b) and wireless WAN (e.g., 2G, 3G) services. The basic components are mobile stations (MSs), BSs/APs, and a core (IP) network (CN). BSs and APs are serving as the communication bridges for MSs as shown in Fig. 4.23.

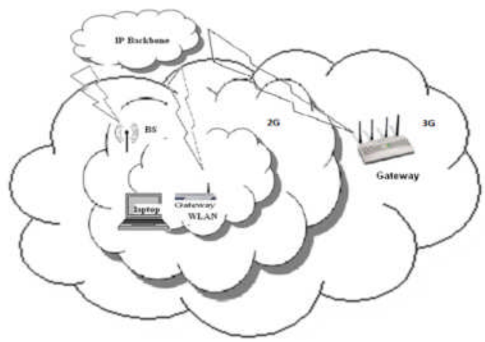


Figure 4.23: Internetworking of 2G, 3G and WLAN network

In this system, GSM as a 2G, UMTS as a 3G network and 802.11b as a WLAN is considered. 2G/3G data services are not able to deliver the same high speed data throughput experience as that provided by WLAN at hot spot locations. If all users decide to download a large chunk of data from internet simultaneously, it will certainly affect the data rates. In case of 2G and 3G, all users will experience lower data rates, while in case of WLAN the effect on data rates is not that significant. The choice between 2G, 3G and WLAN for multimedia services is a matter of interest from the technical point of view.

4.6.2. Network selection based on available bandwidth estimation: In order to select the always best connected network in a given heterogeneous environment, a novel network selection scheme is proposed. The flow graph in Fig 4.24 presents the logic of network selection based on available bandwidth estimation with bootstrap approximation method in heterogeneous environment of 2G, 3G and WLAN networks for multimedia services.

Step 1: Check the presence of networks and then disconnect all available networks. Select any of the disconnected available networks and check its received signal strength. Received signal measurement and calculation described in section 4.3.2.

Step 2: Available bandwidth (ABW) is used as dynamic parameter for network selection in heterogeneous environment described in section 4.3.2.

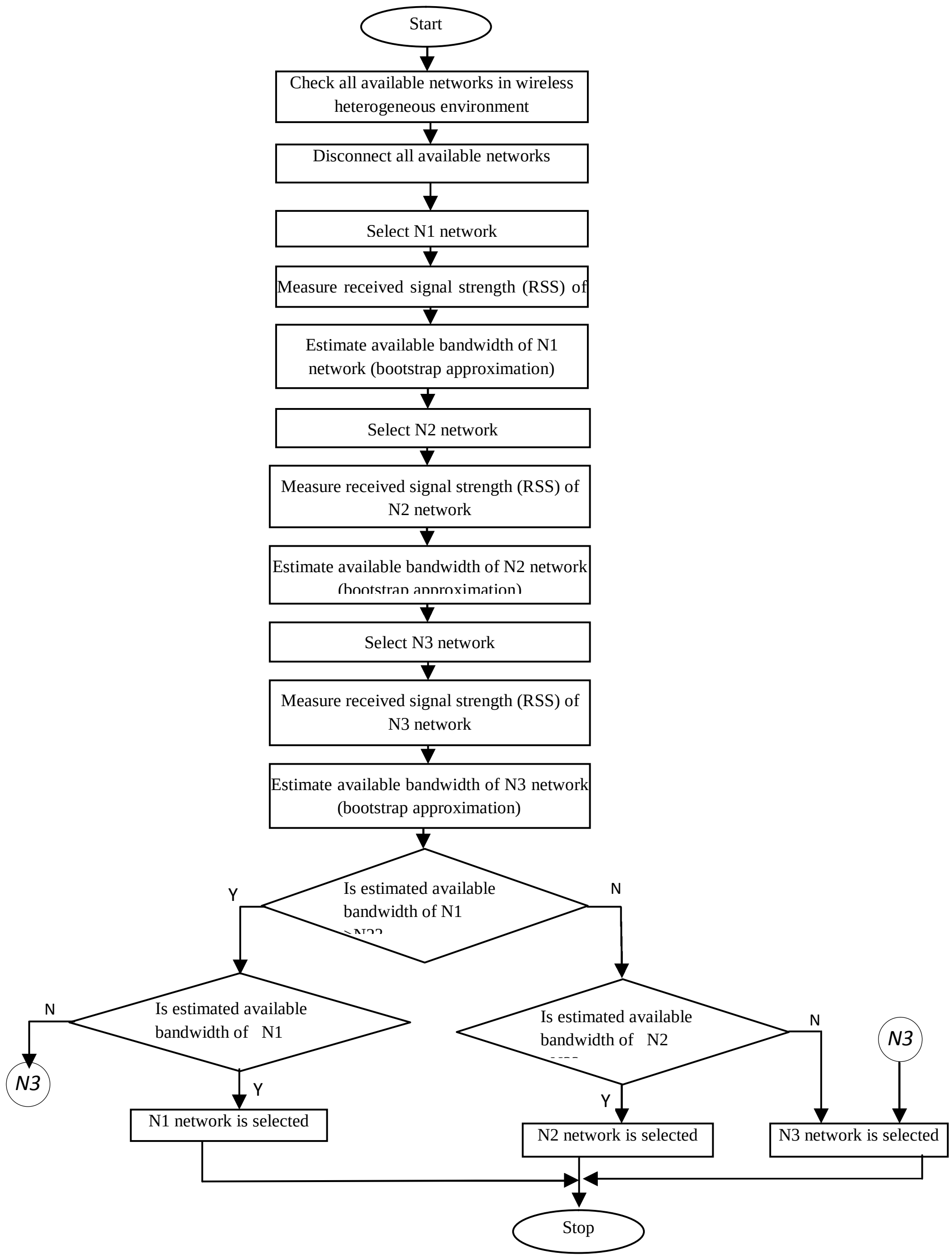


Figure 4.24: Available bandwidth estimation algorithm for network selection in heterogeneous wireless environment.

4.6.2.1. Bootstrap approximation method for available bandwidth estimation: The available bandwidth of the 2G, 3G and WLAN access interfaces is computed as explained in section 4.5.1.1.

Step 3: Compare the calculated available bandwidth with bootstrap approximation of the interfaces b1 (2G), b2 (3G) & b3 (WLAN). Interface having the highest available bandwidth is selected for the real time multimedia services.

The test model supports 2G and 3G Hawaii dongles and WLAN mini card as interfaces of multimode device used for network selection in heterogeneous environment. Multimode client software provides support for automatic roaming across 2G/3G/WLAN, which means that the client can monitor and automatically select 2G or 3G or WLAN network according to the available bandwidth estimation technique.

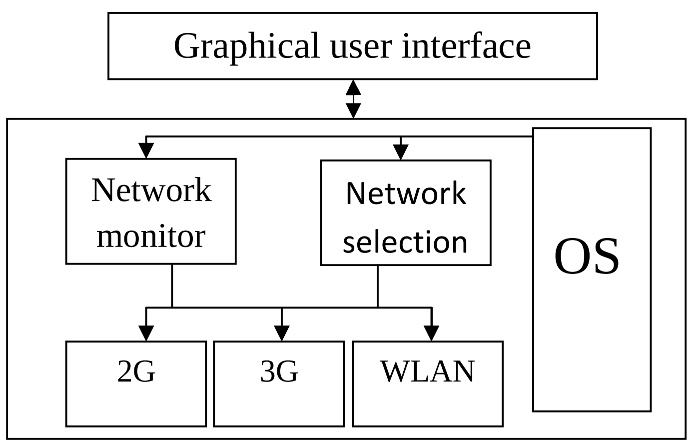


Figure 4.25: Software module of dual mode client

The software system includes a module to monitor and detect different wireless networks and another module for network access selection decision to manage multiple connections in heterogeneous environment.

4.6.3. Experimental setup: We performed field experiments in a commercial wireless network with the experimental scenario as shown in Fig. 4.23 with specifications: sample size n = 5 and number of bootstrap replications B = 10. The estimated available bandwidth at different instances with respective received signal strength of the three considered interfaces is tabulated in Table 4.4. It is observed that the network having more available bandwidth is automatically selected for multimedia services.

Table 4.4: Estimated available bandwidth with received signal strength in heterogeneous environment of 2G, 3G and WLAN networks

S.No	2G (GSM)		3G (UMTS)		WLAN		Network Selection
	RSS (dBm)	ABW (KB)	RSS (dBm)	ABW (KB)	RSS (dBm)	ABW (KB)	Selected network
1.	-76.0	38.79	-75.0	29.83	-48	32.56	2G
2.	-74.0	12.12	-77.0	32.02	-46	47.34	WLAN
3.	-75.0	52.49	-74	87.72	-45	48.66	3G

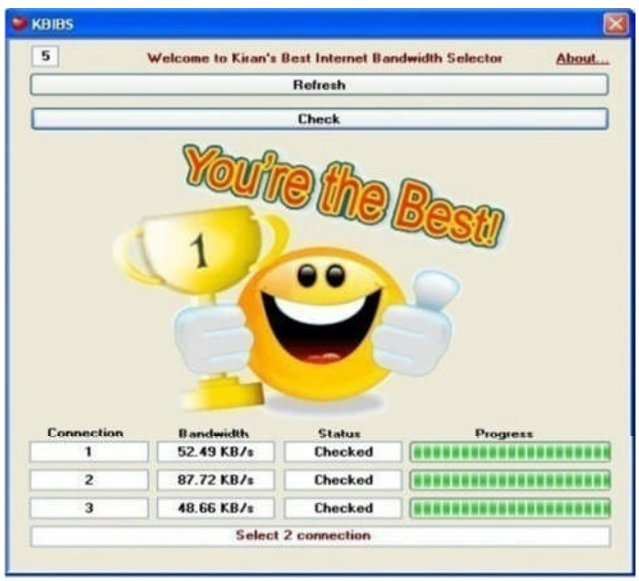


Figure 4.26: User interface of network selection algorithm based on available bandwidth estimation in heterogeneous environment of 2G, 3G and WLAN network.

By comparing the available bandwidth (ABW) estimation, the 2G/3G/WLAN network is selected for multimedia services as per user's preference as shown in Fig 4.26.

4.6.4. Performance evaluation of proposed network selection scheme: To analyze the performance of the network selection technique based on bandwidth estimation by using bootstrap approximation method, we performed a set of experiments with random file sizes (or traffic), locations and time of mobile client. These experiments reflect the performance of the proposed network selection technique. We have evaluated the robustness of proposed network selection algorithm in a commercial area, with no control over the environment and no knowledge about the amount or type of traffic from other users of the network during our experiments.

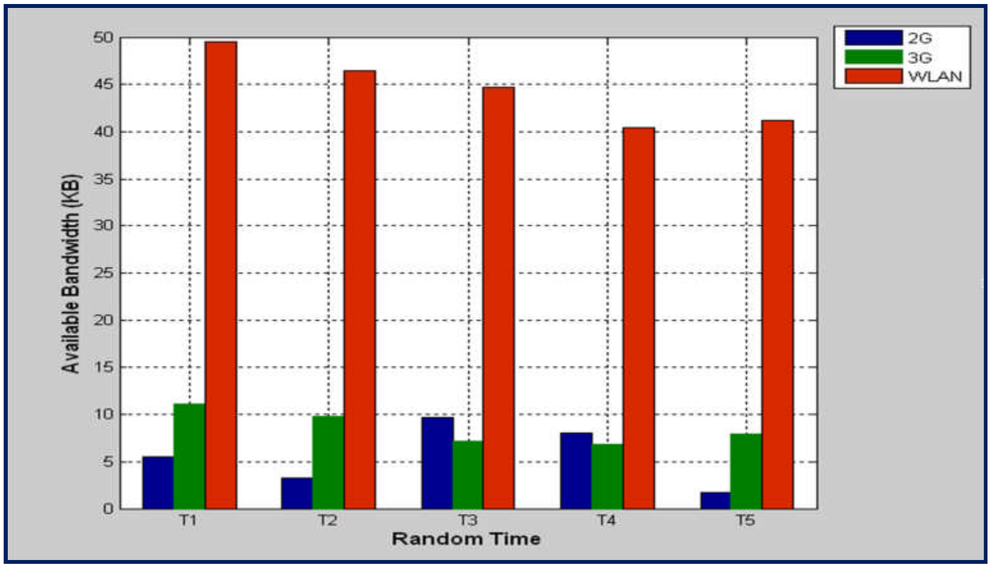


Figure 4.27: (a) Available bandwidth vs. Time

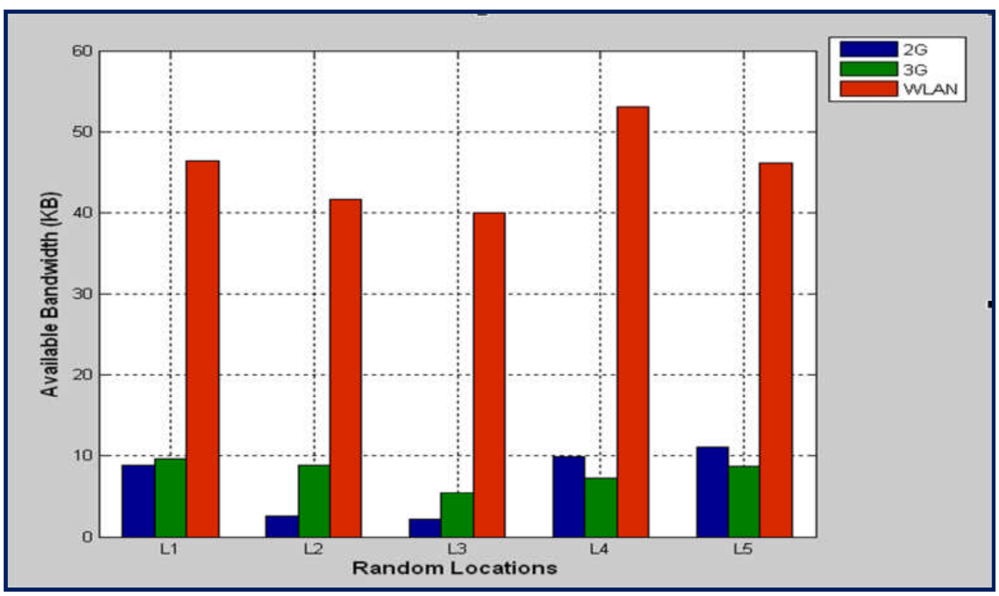


Figure 4.27: (b) Available bandwidth vs. different locations

Case 1: In this case proposed algorithm is tested at random time and locations. Fig. 4.27 (a) & (b) signifies that available bandwidth estimated at random time and location are different, because at any given time or location, the number of user sharing a particular wireless network keeps on changing. As a result the bandwidth shared by users is also different. At any instance or location 2G/3G/WLAN is selected depending upon the status of ABW (Available Bandwidth) at that instant.

Case 2: In this case bootstrap approximation is computed on the basis of size of file to be downloaded which in turn yields the ABW. Fig 4.27 (c) indicates the necessity of meticulous selection of file size to be downloaded. It is evident that estimation of available bandwidth is not feasible for very small file size such as 4KB. However, the gradual increase in file size resulted in satisfactory estimation of available bandwidth. In Fig 4.27 (d) the proportional relation has been observed between the file size and estimation time all the wireless networks available in heterogeneous environment. 2G/3G/WLAN network's available bandwidth estimation time may vary as at any instance the number of user in any of the wireless network is random. Peak traffic makes heterogeneous networks busy which in turn results into slow download speed and proportionate increase in estimation time.

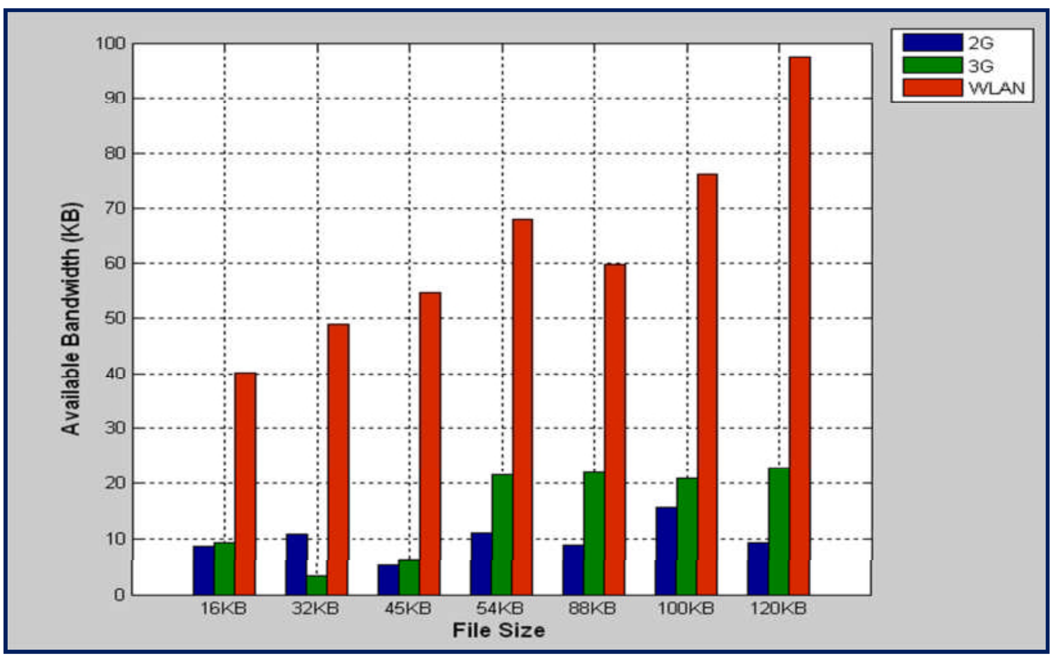


Figure 4.27: (c) File size (traffic) vs. ABW

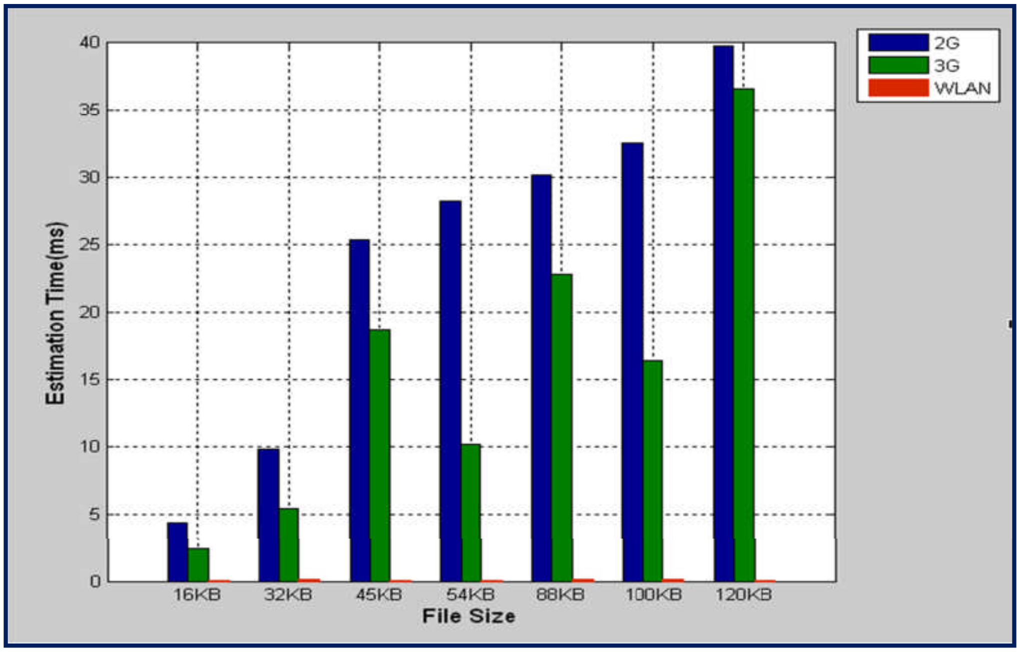


Figure 4.27: (d) File size (or traffic) vs. ABW estimation time

The efficiency of ABW estimation is evaluated on the basis of metrics: estimation error, overhead and reliability described in section 4.5.3.1 to estimate or evaluate the robustness of the proposed algorithm for network selection in heterogeneous environment of 2G, 3G and WLAN.

By using Eq. (4.8), proposed algorithm's ABW estimation error is calculated. It varies usually less than 20% in all networks present in heterogeneous environment (i.e. 2G, 3G, WLAN) except the case where the error can be as high as 100% due to congested link (in peak hours). It is observed that estimation error is less in proposed algorithm in comparison of existing ABW estimation techniques reported in [237].

In proposed algorithm, file size (or traffic) varies from 16 KB to 120 KB and link capacity is considered 144 Kbps, 2 Mbps and 54 Mbps for 2G, 3G and WLAN network respectively. Overhead is calculated by using Eq. (4.9). It is 11.11% to 83% in case of 2G, 0.8% to 6% in case of 3G and 0.03% to 0.22% in WLAN network of heterogeneous environment. In comparison of existing techniques [237], there is less overhead in proposed algorithm's ABW estimation.

Estimation time varies from 0.05 msec to 39.25 msec in proposed algorithm by using file size (or traffic) varying from 16KB to 120KB. It is in range of milliseconds in case of proposed algorithm ABW estimation in comparison of existing tool described in [237].

Reliability is measured by N = 50 (number of trails) and N_0 = 49 (number of estimations) by using Eq. (4.10). Proposed algorithm is 99% reliable and robust algorithm in comparison of existing ABW techniques discussed in [237]. 1% unreliability in ABW estimation creeps in if the file to be downloaded doesn't exist or remote server doesn't respond.

Use of the proposed algorithm ABW estimation is more efficient in comparison to that reported in [237-238] on the basis of relative accuracy (estimation error), overhead, estimation time and reliability which further validates the feasibility of proposed algorithm for network selection in heterogeneous environment of 2G, 3G and WLAN.

4.7. Summary

In this chapter, experimental test bed was developed for network selection based on estimated available bandwidth criteria in heterogeneous wireless networks environment for ubiquitous Internet access and described its real world implementation. Available bandwidth metric is used for network selection due to its intensive demand for multimedia applications (streaming, video chat etc.). Both hardware and software systems are employed for integrated WLAN & 3G networks, WiMAX & 3G, WLAN & WiMAX and 2G, 3G & WLAN standards. We utilize a bootstrap approximation based technique to estimate available bandwidth and compare it with hidden Markov model based estimation to verify its precision. Bootstrap approximation is performed every second with sample size n = 5, number of bootstrap replications B = 10, the number of possible states (N) equal to 5 and number of distinct observation symbols (M) equal to 5 in the HMM estimation. It is implemented for the selection of the best suitable network in the heterogeneous environment consisting of 2G & 3G and 2G, 3G & WLAN standards based wireless networks. It is implemented in temporal and spatial domains to verify its robustness. Estimation error, overhead, estimation time with varying size of traffic and reliability are used as the performance metrics. The available bandwidth estimation in proposed algorithm performs well in terms of estimation error (less than 15%), overhead (varies from 0.45% to 72.91%)

and reliability (approx. 99%) with respect to existing estimation techniques in heterogeneous environment of 2G and 3G. ABW estimation technique based on bootstrap approximation has been implemented for proposed network selection which outperforms the existing techniques in terms of estimation error (less than 20%), overhead (varies from 0.03% to 83%) and reliability (approx. 99%) in heterogeneous environment comprising of 2G, 3G and WLAN. The proposed algorithm's ABW estimation is more efficient in comparison to existing on the basis of relative accuracy (estimation error), overhead, estimation time and reliability which further validates the feasibility of proposed algorithm for network selection in heterogeneous environment of 2G and 3G. The results of the proposed algorithm are better in term of estimation time, which further justifies the validity of the algorithm.

CHAPTER 5

NETWORK SELECTION ALGORITHM BASED ON LINK QUALITY PARAMETERS

5.1. Introduction

In this chapter, we propose network selection algorithms based on link parameters. These parameters include averaged received signal strength, outage probability, bit error rate, available bit rate, achievable throughput, signal to noise ratio and distance, assuming that these network conditions are dominant in network selection. The first proposed algorithm based on link parameters comprises of two stages. In first stage, overlapping region is identified through distance estimation. Network selection algorithm based on averaged received signal strength plus outage is invoked in second stage to select the optimum network between two disparate networks- GSM and UMTS. The predicted overlapped distance is utilized to make a network selection in order to minimize the probability of network selection failures or unnecessary selections. The second algorithm utilizes signal strength, available bit rate, signal to noise ratio, achievable throughput, bit error rate and outage probability as criteria for network selection. The selection metrics are hybridized with PSO for relative dynamic weight optimization. The proposed algorithm is executed in a typical heterogeneous environment of EDGE (2.5G) and UMTS (3G). Further a network selection algorithm based on the same platform for a heterogeneous environment consisting of WiMAX and LTE standard is presented. It is based on received signal strength, signal to noise ratio, available bit rate, achievable throughput and bit error rate. Relative weights of the decision making attributes are optimized employing PSO approach. The number of satisfied users is calculated on the basis of wireless network selected by proposed algorithm. It is further optimized by modified PSO and affirmed by Monte Carlo method.

5.2. Network selection algorithm in heterogeneous environment of GSM and UMTS

To select the best suitable wireless network in heterogeneous environment is a key issue towards realizing ubiquitous connectivity. Presently 2G and 3G networks coexist to accomplish the requirements of service and different coverage targets. It is desired by the user to handle both the network uninterrupted in the ongoing service. This requires the selection of an optimal network. Network selection can be initialized by MS or can be based upon measurements of link quality by the network. RSS is one of the most widely used parameters for network selection. It is generally seen that Ping-Pong effect results from the selection based on thresholds of received signal strength. Low network throughput, long handoff delay, and high dropping probability are effects of the Ping-Pong effect. Outage probability is another important parameter for network selection in multimedia applications. It is determined on the basis of receiver sensitivity or minimum acceptable signal strength. It is defined as the probability when the instantaneous received signal strength falls below a certain threshold. The location information of MS as provided by GPS (Global Positioning System) has motivated us in making the network selection decision in addition to link parameter measurements. Network selection in heterogeneous wireless environment is proposed on the basis of distance estimation and different link parameters (RSS, outage probability).

5.2.1. The system model: Heterogeneous environment consists of n_i, i = 1, 2, 3…N different wireless networks. For sake of convenience, we have taken into the consideration GSM and UMTS cellular networks as shown in Fig. 5.1.

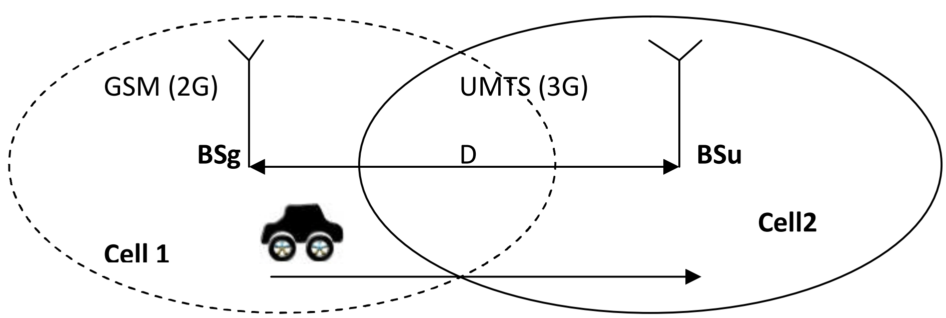


Figure 5.1: Heterogeneous wireless network model

We assume that a user is traveling at a constant speed in a straight line from the base station 'BS_g (2G)'to the base station 'BS_u (3G)'and the distance between the two base stations is 'D'. MS observes the received signal strength at regular distance intervals as

$$d = kd_s \tag{5.1}$$

where k, an integer with $k \varepsilon [0, D/d_s]$ and d_s is the sampling distance (d_s= 1m) [24]. Both of the base stations are assumed to operate from the center of their respective cells.

Assuming that, MS initially lies in the coverage area of either GSM or UMTS. Due to mobility, it moves into the overlapping regions, i.e. simultaneously within the coverage area of both GSM (BS_g) and UMTS (BS_u). In order to overcome this dilemma network selection algorithm is proposed to select the network within the overlapped region.

In proposed algorithm first selection parameter is averaged RSS. RSS constitutes path loss attenuation with respect to distance, fast fading and shadow fading. The key issue of received signal strength is path loss which can be evaluated by propagation path loss models [241-242]. The pilot signal strength received by MS from BS_g and BS_u respectively can be expressed in dBm as:

$$S_g (k) = K_1 - 10\gamma_g \log_{10}(kd_s) + \xi_g \quad (5.2)$$

$$S_u (k) = K_1 - 10\gamma_u \log_{10}(D - kd_s) + \xi_u \quad (5.3)$$

Here, the path loss parameter is K_1 and the path loss exponents for GSM and UMTS cell environments are γ_g and γ_u, respectively. Buildings, hills, trees and foliage form an obstruction for the line of sight path between transmitter and receiver, cause shadowing; hence transmitted signal is blocked due to severe attenuation. The relative positions of the transmitter and receiver with respect to the large obstacles in the propagation environment construct the amount of shadow fading. In above equations (5.2) and (5.3), the shadow fading components are signified by ξ_g and ξ_u. The auto correction function of shadow fades is notified as

$$E \{\xi (k) \xi (k + m)\} = \sigma_s^2\alpha |m| \quad (5.4)$$

$$\alpha = \exp (-\nu T_m/d_0) \quad (5.5)$$

Where σ_s is the standard deviation of shadow fading and m is an integer. The same value of standard deviation σ_s for both cells is assumed. d_0 is the correlation distance, T_m is the sampling time, and ν is velocity of the MS; hence $d_s = \nu T_m$ [243]. To reduce the multiple time network selection at the same time instance and to mitigate the outcome of shadow fading, the measured signal strength samples are averaged over a rectangular window before these could be used to select the network, which is given as follows [244]

$$S_{ai}(k) = \frac{1}{N_w}\sum_{n=0}^{N-1} S_i(k-n)W_n \qquad i=1,2 \tag{5.6}$$

Where after grading and equating, the k^{th} sample known as S_{ai} (k). The sample taken at the end of the $(k-n)^{th}$ interval is ascribed a weight denoted by

$$N_w = \sum_{n=0}^{N-1} W_n \tag{5.7}$$

For a rectangular window, equal weight is given to all the precedent samples in the averaging window Nw therefore, Wn = 1 for all n. Fast fading is due to multipath reflection of a transmitted wave by objects such as houses, buildings other manmade contour, natural objects such as forests surrounding the MS. It is neglected for network selection commencement trigger due to its short correlation distance relative to that of shadow fading. Standard deviation of averaged shadowing samples can be obtained as [245],

$$\sigma^2 = \frac{\sigma_s^2}{N}\left[1 + 2 \times \sum_{n=1}^{N-1}\left(1-\frac{n}{N}\right)\rho^n\right] \tag{5.8}$$

Where, σ_s and σ are the respective standard deviations of shadow fading before, and after taking average of signal strength measurements over N samples. The symbol 'ρ' denotes auto-correlation coefficient of the shadow fading.

Distance as another selection parameter is used to identify the overlapped region for network selection in heterogeneous environment to reduce burden on MS. In order to maintain low complexity, we ascertain Gaussian statistics for distance measurement variables d_i (i = 1, 2). The expected distance of MS from BS_g and BS_u are enumerated as follows

$$d_1(k) = kds + \chi_g, \tag{5.9}$$

$$d_2(k) = D - kds + \chi_w, \tag{5.10}$$

where χ_g and χ_w are compiled as zero mean independent wide sense stationary Gaussian random processes representing distance measurement errors with standard deviation σ_d. Average distance measurement error increases with σ_d. Assuming 50m of maximum error tolerance, σ_d = 50m is used in the replica for numerical data processing [246]. It reflects importance of the measurement error at any sampling point. Relative distance of MS from the two BSs is defined as

$$X(k) = d_1(k) - d_2(k) \tag{5.11}$$

When the operator plans a system, the outage probability distributed in a cell is normally designed within the some limit for a certain traffic load (voice, data, video or multimedia etc.). There are two possible cases in existing circuit switched cellular networks, first the outage level has reached the maximum acceptable value and second the outage level is below the maximum acceptable value [247]. So we consider another parameter for network selection algorithm that is outage probability. It is a probability which calculates that how many times the averaged received signal strength is less than a certain threshold. It is defined as

$$P_{out} = P[\Gamma < \Gamma_t] \tag{5.12}$$

Γ is received signal strength of wireless network present in heterogeneous environment and Γ_t is the threshold received signal strength. The threshold depends on the impact of wireless network types in heterogeneous environment [248].

For numerical computation, the main system specifications typically for proposed network selection algorithm based on averaged RSS, distance and outage probability have been chosen as shown in Table 5.1.

For exposition convenience, we consider the radius defined in Table 5.1 for both the cellular networks present in heterogeneous environment. Different path loss characteristics are chosen for each cellular network. Path loss exponent is lower in GSM cell, resulting in considerate deviation of signal strength with respect to distance as correlated to UMTS cell. RSS thresholds are the values of RSS available from BSg and BSu at cell boundary consequently due to deterministic path loss component only.

Table 5.1: System parameters for simulation model

S.No.	System Parameters	Values
1.	Radius of GSM (R_g)	1,000 m
2.	Radius of UMTS (R_u)	500 m
3.	Path loss exponent of GSM (γ_g)	3.0
4.	Path loss exponent of UMTS (γ_u)	3.4
5.	Standard deviation of shadow fading σ_s	8 dB
6.	Sampling distance (d_s)	1 m
7.	RSS threshold for GSM network outage	-88 dBm
8.	RSS threshold for UMTS network outage	-94dBm

5.2.2. Proposed algorithm for network selection: The proposed algorithm identifies the best available wireless network while maintaining QoS for multimedia services in heterogeneous wireless environment. As discussed in earlier section, averaged RSS, distance and outage probability parameters are used to perform the network selection. If averaged RSS of any network is high and outage probability is less with respect to another network in overlapped region estimated by distance in heterogeneous environment, then that network is selected as the best suitable network.

$$NSF_{(i)}= F(S_{a(i)}(k)>S_{a(i+1)}(k)) \text{ AND } F(S_{a(i)}(k)>S_{th}(k) \text{ AND } F(Pout_{(i)}(k)<Pout_{(i+1)}(k)) \text{ AND } F(Pout_{(i)}(k)<Pout_{th}(k)) \text{ AND } F(d_{(i)}(k)>d_{th}(k)) \quad (5.13)$$

where, $S_{a(i)}$ denotes the averaged RSS from access networks. S_{th} indicates the averaged RSS threshold. k=1,2,3,……….,D is used to choose sample of averaged RSS and outage probability at various sampling distances. $Pout_{(i)}$ denotes outage probability of wireless network in heterogeneous environment and $Pout_{th}$ represents threshold outage probability value for multimedia services. $d_{(i)}$ defines distance of mobile user from its respective base station (BS), where d_{th} represents overlapped boundary threshold distance. i=1,2,………..N-1 for wireless network present in heterogeneous environment as shown in Eq.(5.6). The function F (.) is an entity step function. The unit step function is an incoherent function whose value is zero for negative contentions and one for positive contentions. AND is a logical operator. Network Selection Function (NSF) yields null value if any of the condition in Eq. 5.13 is not satisfied. NSF_1 and NSF_2 denote 2G and 3G wireless network respectively in above defined heterogeneous wireless network environment.

The flow chart of the logic of network selection based on averaged RSS, distance and outage probability for selecting the network in composite context for multimedia assistance is represented in Fig. 5.2. In an overlaid network consisting of multiple access technologies, network selection can be made at any point of time and distance as per the requirements of the network conditions, quality of service requirements for the application and user preference. However, in the present work, we assume that network conditions (averaged RSS and outage probability) dominate the decision of network selection. In a dynamic radio propagation environment, network conditions vary with time and distance. In such scenario, we have defined an area of interest for making network selection around the coverage boundaries of the two networks. This area of interest has been limited by the distance vector as defined by Eq. 5.11.

Proposed network selection criterion is divided into two stages. In first stage overlapped area is identified and link parameters averaged RSS and outage probability are calculated in second stage. Because of multimode mobile device facility, the user can access number of wireless networks together [249]. Two interfaces of MS are considered which can access 2G and 3G networks. The selection of network also relies upon the application running at that instant. If the application established on multimedia services then the primary concern is less outage probability as to reduce data loss in critical/secure usage like online banking transactions. Overall planning of the network depends on user preferences, network conditions (more averaged RSS and less outage probability) and overlapped region.

Initially check the networks present in heterogeneous environment of multimode MS. It comprises tracking and observing radio link quality and conducive processing of link quality measurement.

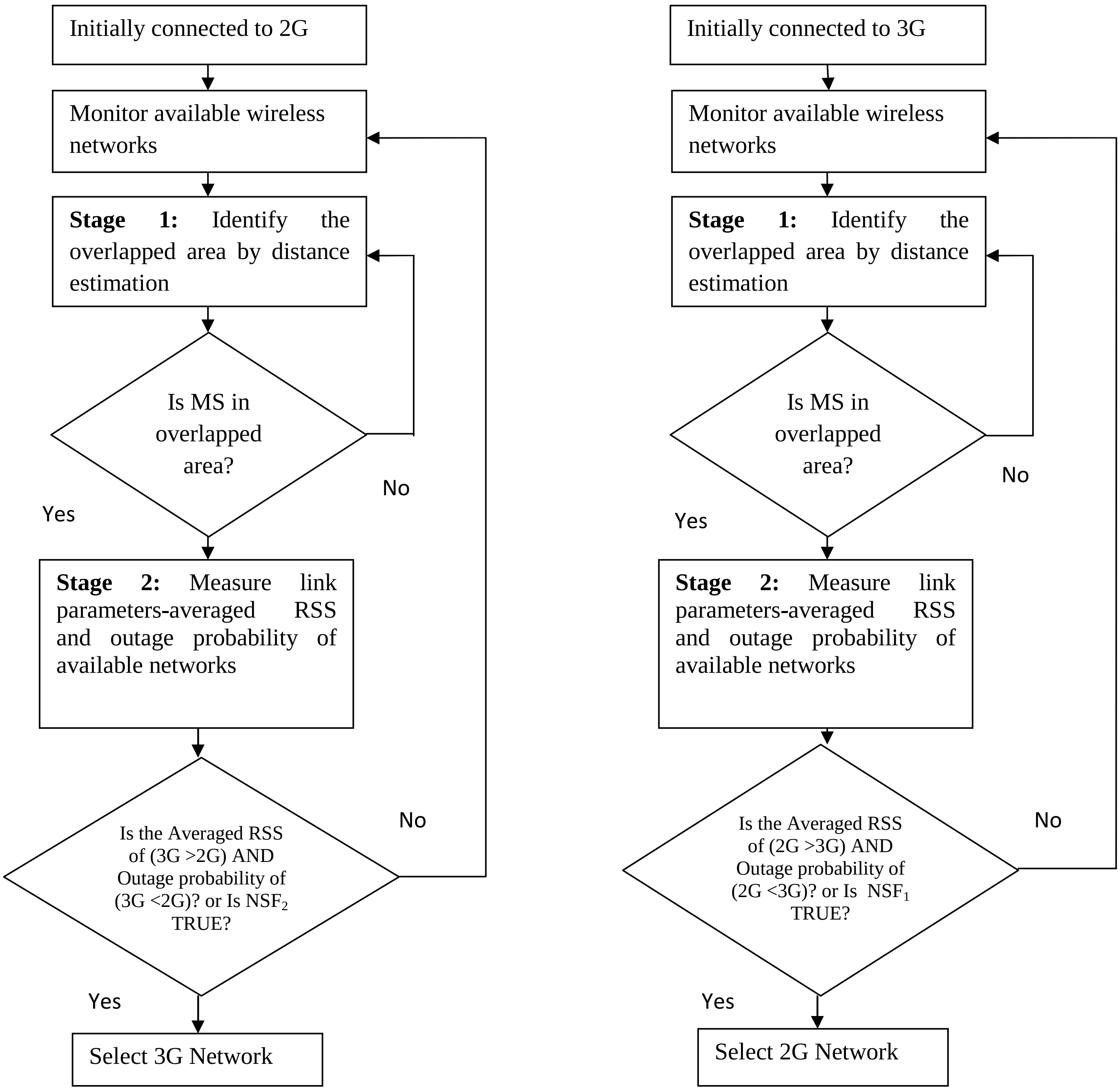


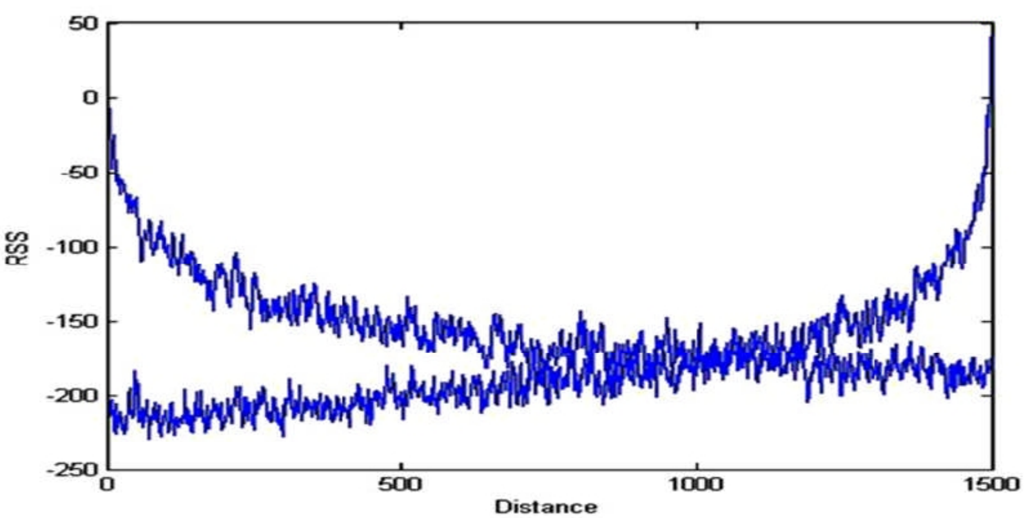
Figure 5.2. Proposed algorithm for network selection in heterogeneous environment of 2G and 3G

Stage 1: The network selection commencement point in the process is the combination of RSS and distance. RSS is initially used to discover the wireless network present. If the MS is having only single wireless network then it is automatically connected through it. But when the MS catches more than one wireless network at the same time then the problem of network selection comes into the picture for the best QoS. Distance parameter is used to search the overlapped area to reduce overhead over the MS for network selection throughout the distance from the respective base station.

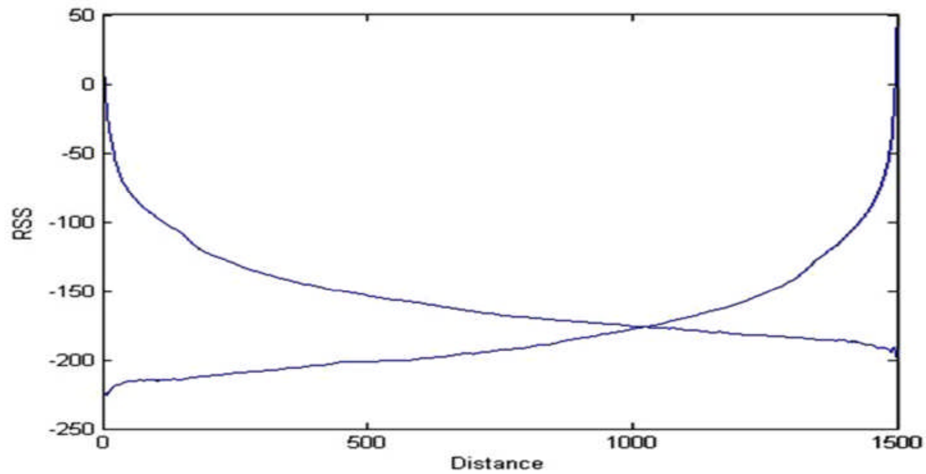
Stage 2: The proposed algorithm is employing combination of averaged signal strength and outage to perform a network selection between BS_g and BS_u in second stage. According to the proposed algorithm, first calculate the averaged RSS of both the networks present in heterogeneous environment. Then calculate the outage probability on the basis of averaged RSS and its threshold value. Here, averaged RSS and outage probability (link parameters) have been used as the metrics to select network in overlapped region.

The network having greater averaged RSS and lesser outage probability is selected as the best in the given heterogeneous environment under consideration as shown in Fig 5.2.

5.2.3. Results and discussion: The evaluation of the network selection algorithm has been performed as the MS moves with a constant velocity along a straight line trajectory between two BSs. Further for numerical computation, the typical values of system parameters falling in the range of practical interest have been taken as shown in Table 5.1. The received signal strength (which consists of path loss and shadowing) for both the wireless networks with respect to distance are shown in Fig 5.3.



(a)



(b)

Figure 5.3: (a) RSS (dBm) vs. Distance (m) **(b)** Averaged RSS (dBm) vs. Distance (m) in wireless heterogeneous environment of 2G and 3G

The randomness of shadow fading, results in change of the RSS and outage. This yields serious Ping-Pong effect when a mobile station moves around the overlay area of heterogeneous wireless networks. The ping pong effect causes redundant network selection and brings some limitation including high dropping probability, long handoff delay and low network throughput. The choice of averaging window size (N) is critical in the design of network selection algorithm for microcellular based networks. These networks require fast selections since timing is very critical issue due to fast signal level variation. Greatly smoothed version of signal strength may not detect the timely need of network selection and may lead to undesired network selection. Smaller N yields early network selections. Consequent to this, respective number of averaging samples in Eq. 5.7 are chosen as $N = 20$ for both GSM and UMTS cells to get the acceptable value of outage probability. Fig 5.3(b) represents averaged RSS with respect to distance by using moving averaging filter concept.

Decrease in RSS due to increase in distance in both the wireless networks can be observed in Fig. 5.3. Analytically, the network selection condition occurs when the overlapping zone of wireless network comes into the entity. Network selection from BS_g to BS_u should be within 100m of the cell boundary in GSM cell. This setting predicts that network selection may take place when MS is greater than or equal to 900m away from BS_g. Given R_g (radius of GSM cell) = 1,000 m and R_u (radius of UMTS cell) = 500 m, this condition implores $d_0 \geq 900$m and $d_1 < 600$m as enumerated by Eqs. 5.9 and 5.10, which give the distance of MS from BS_g and

BS_u consequently. Subsequently Eq. 5.11 gives X ≥300m for network selection from BS_g to BS_u. Similarly, in order to switch network selection from BS_u to BS_g, it has to be within 100m of the cell boundary in UMTS cell. This context implies that network selection may take place when MS is greater than or equal to 400m away from BS_u. This condition requires d_1≥400m apart from BS_u. In turn, MS is less than or equal to 1,100m from BS_g and, therefore, relative distance X <700 m. These settings are based on the attainment that ±100m is the overlapped region between two cells.

In conventional method, received signal strength is the only dominant parameter for network selection. Due to the conventional selection method multiple time network selection occurs. This condition increases the overheads. So there is need to consider distance estimation for overlap region calculation and outage probability parameter in addition with the averaged RSS to make the final decision about the best network selection in heterogeneous environment.

Fig. 5.4 represents outage probability vs. distance graph in heterogeneous wireless environment. As the MS moves away from the base station the outage probability increases which varies from 0 to 1. The MS which receives greater averaged RSS and lesser outage to the MS is selected as the best network in wireless overlapped heterogeneous region. Network selection for multimedia services requires minimum outage probability to be ≈ 0.2 [250].

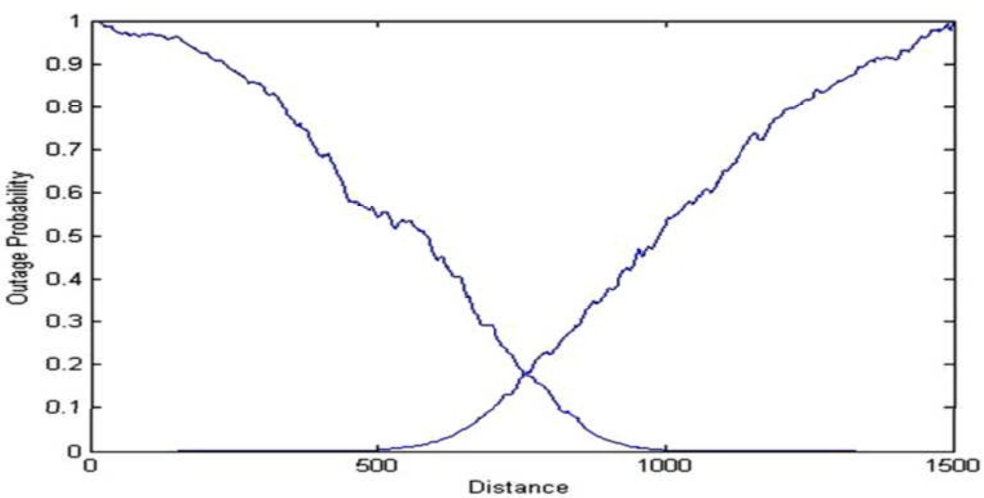


Figure 5.4.: Outage probability vs. distance (m) in wireless heterogeneous environment of 2G and 3G

5.2.3.1. Performance evaluation of proposed algorithm: When MS moves from BS_g to BS_u and similarly, from BS_u to BS_g then evaluation is performed with the proposed network selection algorithm as well as conventional method. Network selection rate and network selection delay have been used as the metrics to evaluate performance of the proposed network selection algorithm with respect to conventional method. Network selection rate is defined as the expected number of selections MS experiences while traversing a trajectory from one network to another. This performance measure represents switching load associated with the network selection process. Ideally, there should be one selection across the cell boundary. Network selection delay is marked by the position of first selection on the mobile trajectory [21].

Case 1: In this case different RSS thresholds are chosen as $T_{gsm} = -88dBm$ and $T_{umts} = -94dBm$. Network selection rate is enumerated for different values of T_{umts}, which is varied from -106 *to* $-74dBm$, while keeping $T_{gsm} = -88$ *dBm*. For conventional method based on RSS only, the network selection rate equal to 6.299 is accomplished at $T_{umts} = -94$ *dBm,* while proposed algorithm based on distance, averaged RSS and outage probability yields network selection rate equal to 1.999. It is evident from Fig. 5.5 (a) that there is a significant reduction in network selection rate with the application of proposed algorithm. It is around 68% with respect to conventional method. Due to this noticeable improvement in network resource efficiency can be achieved by using the proposed algorithm.

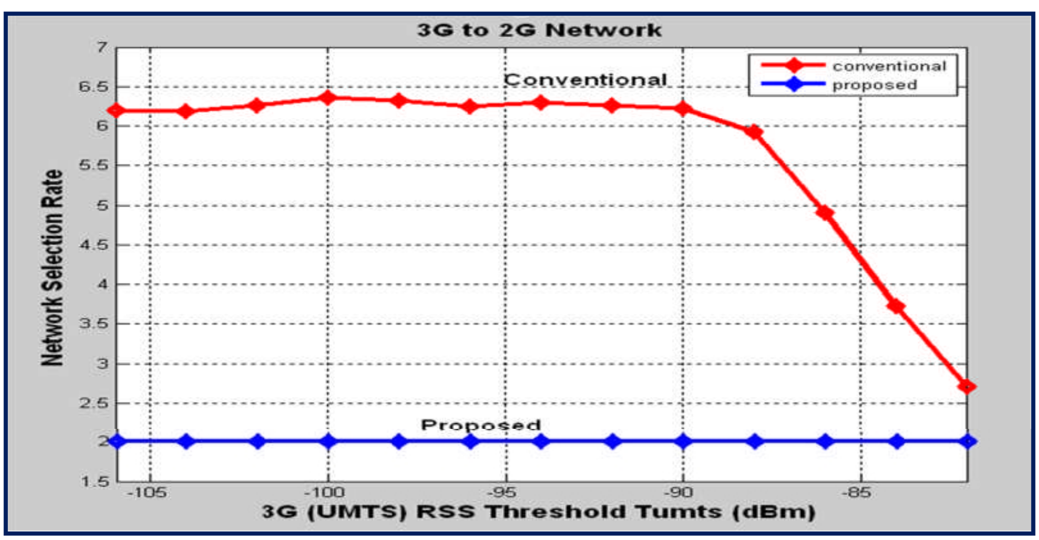


Figure 5.5: (a) Network selection rate vs. threshold at fixed T_{gsm} = -88 dBm

Case 2: The impact of RSS threshold setting of T_{umts} on network selection delay metric is credible by using Fig. 5.5 (b). Greater value of T_{umts} will delay the selection process and hence degrades the communication link quality from the serving BS_u. For smaller T_{umts}, early selection will be encouraged. Proper value of T_{umts} setting should be chosen according to the link quality requirements. Fig 5.5 (b) depicts the network selection delay with respect to UMTS RSS threshold. By applying conventional algorithm, network selection can be initiated within 615m to 1496m and with proposed algorithm, network selection can be initiated within 653m to 1495m by setting $T_{umts}= -74$ to -106 dBm. As such, under proposed algorithm, network selection can be conscripted at 1002m by setting T_{umts} = -94 dBm as per selection conditions in overlapped area. Reducing network selection delay reduces call dropping probability and hence improves QoS as anticipated by the user.

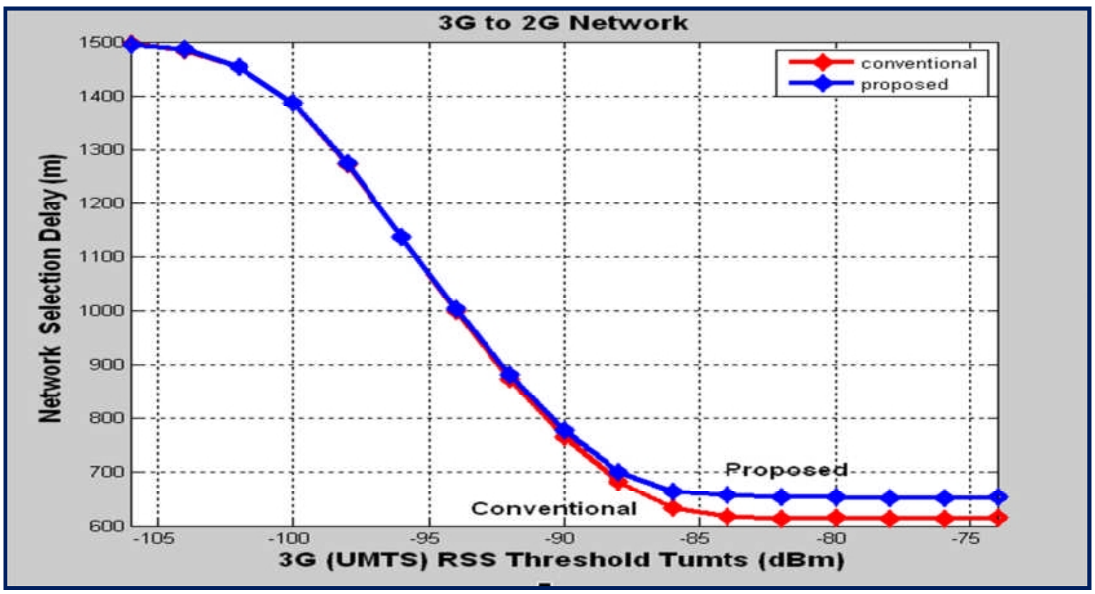


Figure 5.5: (b) Network selection delay vs. threshold at fxed T_{umts} = -94 dBm

Case 3: In this case network selection rate is enumerated for different values of T_{gsm}, which is varied from -94 *to* -72 *dBm*. It is observed that keeping $T_{umts} = -94$ *dBm*, network selection was computed for different perspective of signal strength threshold T_{gsm}. For conventional method, at the attributing value of $T_{gsm} = -88 dBm$ the network selection rate equal to 6.301 is attained while on the other hand, proposed algorithm yields network selection rate equal to 2. As seen in Fig. 5.5 (c), there is a significant reduction of 68% in network selection rate under proposed algorithm. It automatically improves networks resource efficiency.

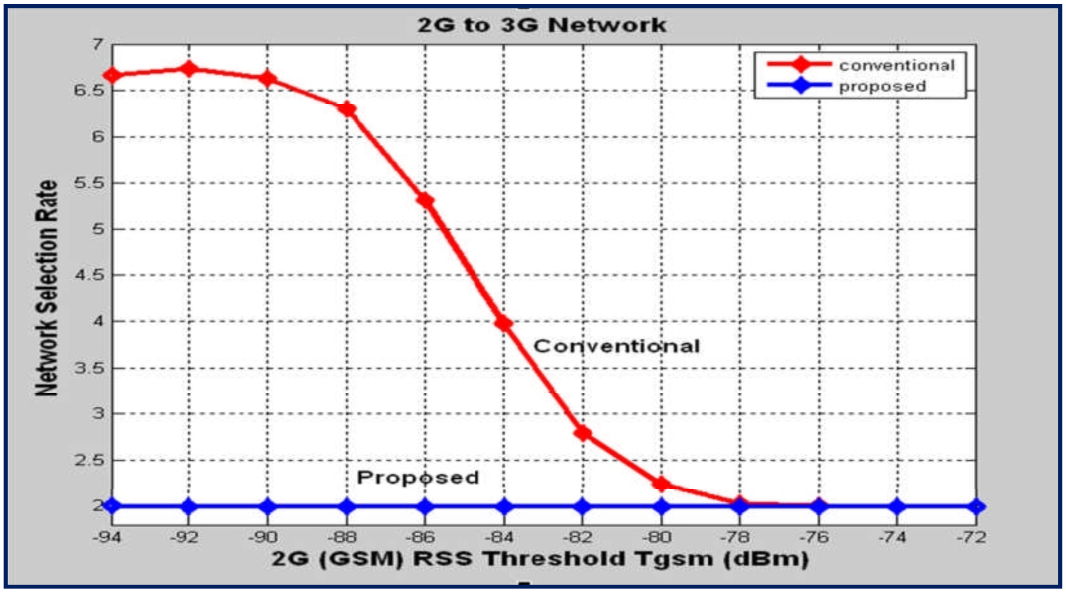
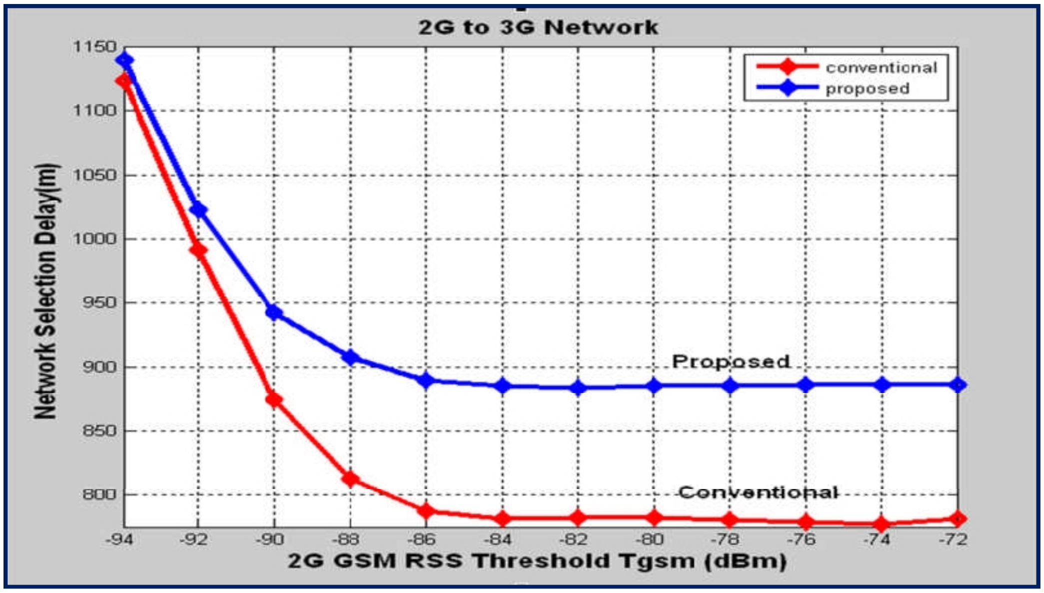


Figure 5.5: (c) Network selection rate vs. threshold at fixed T_{umts} = -94 dBm

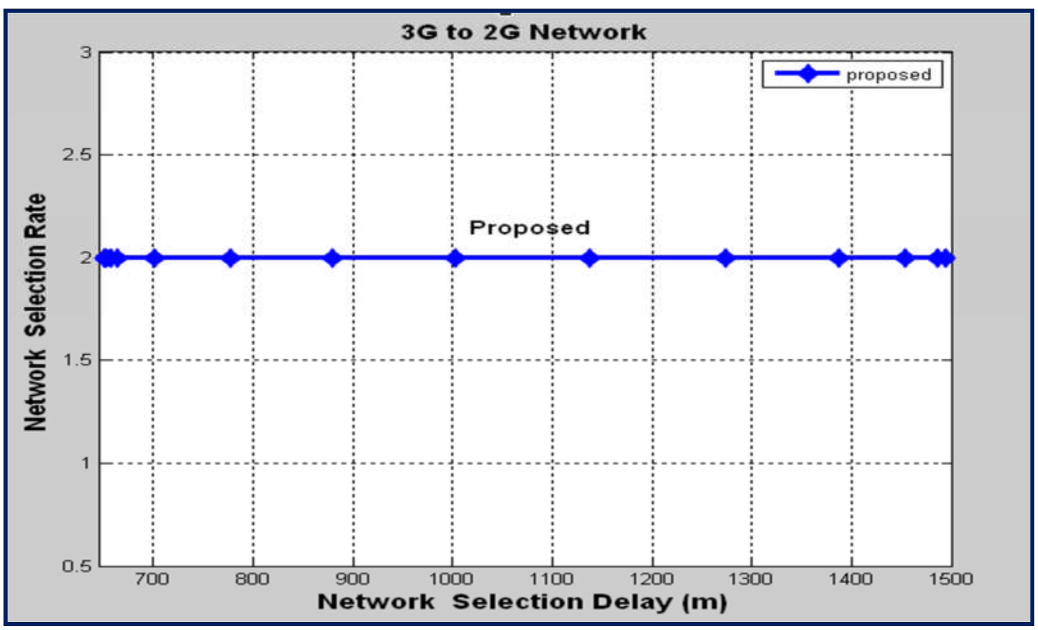
Case 4: In this case proper value of T*gsm* setting is chosen according to the link quality requirements. Fig 5.5 (d) clarifies the network selection delay with respect to GSM RSS threshold. Under proposed algorithm, network selection can be initiated within 886m to 1139m and by conventional algorithm network selection can be initiated within 781m to 1123m by setting $T_{gsm}= -72$ to -94 dBm. In analogy, by conventional algorithm network selection can take place at 991m by setting T_{gsm} equal to -92dBm whereas, network selection can take place between 907m and 1022m by setting T_{gsm} from -88dBm to -92 dBm in proposed algorithm. Due to reduction in link quality from BS_g, T_{gsm} equal to -88dBm is preferred.

Case 5: Tradeoff as shown in Fig. 5.5 (e) & (f) plotted between network selection delay and network selection rate are used to optimize the network selection attainment. Following the requirements that network selection should initiate at or around the cell boundary (1,000m away from BS_g), T_{umts} and T_{gsm} can be set in accordance to the discrete curves for the proposed algorithm.



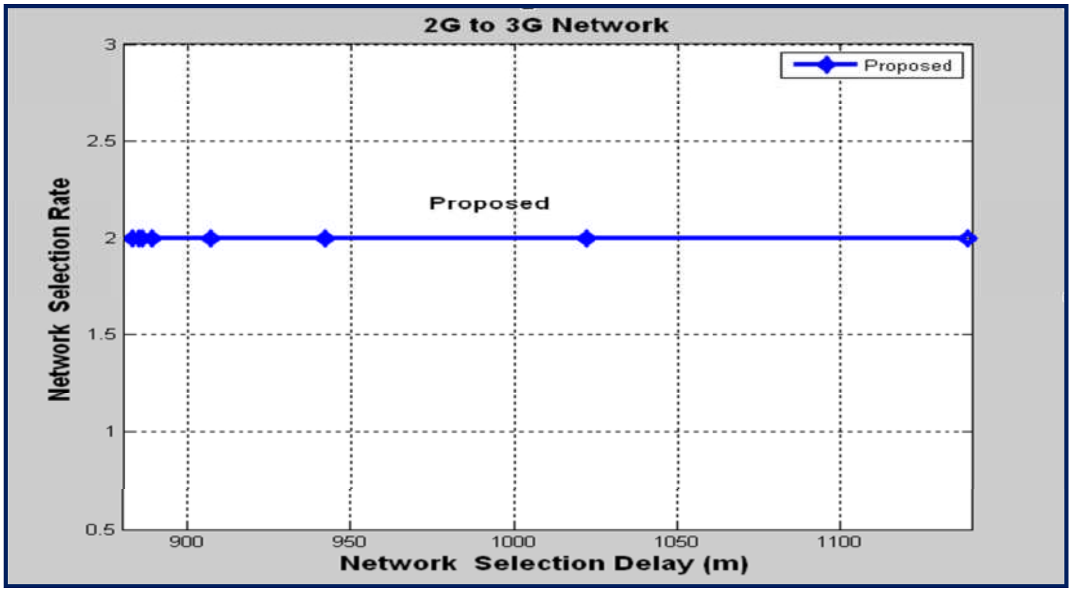
(d)

Figure 5.5: (d) Network selection delay vs. threshold at fixed T_{gsm} =-88 dBm



(e)

Figure 5.5: (e) Trade off curves while moving from 3G to 2G network



(f)

Figure 5.5 (f) Trade curves while moving from 2G to 3G network

The above results show the improved performance of the proposed network selection algorithm for intersystem working. Reduction in network selection rate leads to less overhead of signaling and switching process on the cellular network. Undoubtedly, more resources are available to carry the traffic load, leading to less blocking and, therefore, improved QoS.

When the velocity (v) of MS is being considered then the performance evaluation is done on the basis of the two metrics i.e. probability of network selection failures and probability of unnecessary network selection. A network selection failure occurs if the traveling time inside the overlapped area is shorter than the selection latency τ_i from one cellular network to another cellular network, i.e., the traveling distance *d* is smaller than $v\tau_i$. If the MS's traveling time inside the overlapped area is smaller than the sum of the network selection time into (τi) and out of (τo) the region (i.e., the traveling distance *d* is smaller than $v(\tau i+\tau o)$), the network selection to the next cellular becomes unnecessary.

To analyze the probability of network selection failures and unnecessary selections (N_u) for different network selection methods, it is assumed that the target N_f (probability of network selection failures) and N_u (probability of unnecessary network selections) are 0.02 [251] and 0.04, respectively. For this analysis we have further presumed the coverage radius of the heterogeneous wireless network R_h equal to 1500 m and the network selection latencies of both the cellular networks from 2G to 3G and from 3G to 2G cellular network, $\tau i = \tau o$ equal to 1s as in [16]. The formulae for probability of network selection failures and probability of unnecessary network selections have been derived from handover probability of failures and unnecessary handovers defined in Mohanty's [16] and Varma's [252] methods. Network selection probability of failure is given by Eq. (5.14)

$$N_f = 1 \qquad\qquad v\tau_i > 2R_h$$

$$= \frac{2}{\pi} sin^{-1} \left(\frac{v\tau_i}{2R_h}\right) \qquad\qquad 0 \le v\tau_i \le 2 R_h \qquad (5.14)$$

Where, the unnecessary network selection probability is given by Eq. (5.15)

$$N_u = 1 \qquad\qquad (\tau_i + \tau_o) > 2R_h \qquad (5.15)$$

$$= \frac{2}{\pi} sin^{-1} \left(\frac{(\tau_i + \tau_o)}{2R_h}\right) \qquad\qquad 0 \le v(\tau_i + \tau_o) \le 2 R_h$$

The comparison of existing algorithm of Varma's, Mohanty's [16, 252] and proposed methods are shown in Fig. 5.6 (a) and (b), respectively. Since proposed system is designed to keep the probabilities below preset levels, even though the speed of the MS increases, the probabilities remain the same.

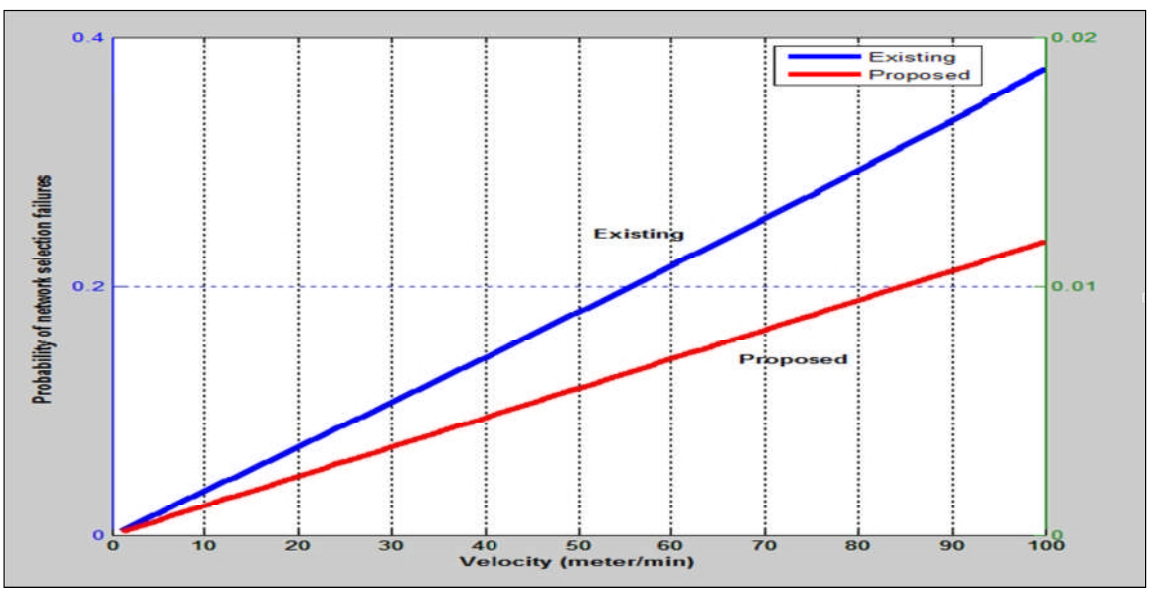


Figure 5.6 (a) Velocity of MS vs. Probability of network selection failures

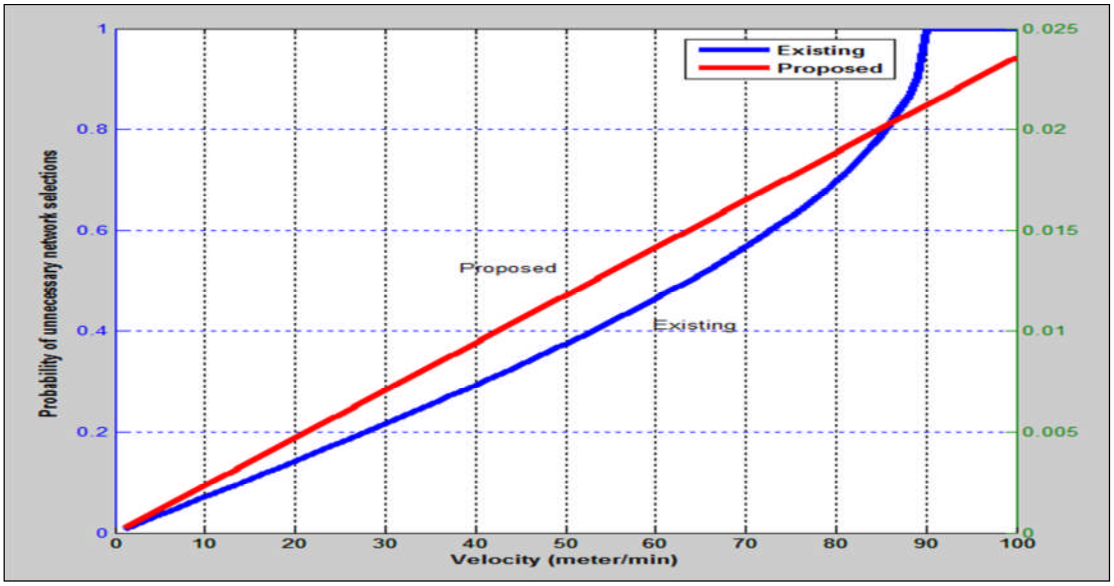


Figure 5.6: (b) Velocity of MS vs. Probability of unnecessary network selections

As illustrated by the Fig. 5.6 (a) & (b), for higher speeds, proposed algorithm yields lower probability of network selection failures and unnecessary selections than the other existing methods. Otherwise, only for velocities less than 10 km/h, Mohanty's and Varma's methods yield marginally better results.

5.3. Network selection Optimization

We focus on the selection of always best connected (ABC) network in heterogeneous environment while maintaining QoS for multimedia services. Heterogeneous environment may consist of number of overlay wireless technologies. Proposed network selection model is represented in Fig 5.7.

Initially monitor the networks present in heterogeneous environment of multimode MS. RSS is used to sense the presence of wireless networks. If the MS detects a single wireless network (WN_1) then it is automatically connected to it. But when the MS senses more than one wireless network (such as WN_1,……..,WN_n) at the same time, then the problem of network selection comes into the picture for the best QoS. In the proposed model, first observes the physical layer metrics (such as averaged RSS, outage probability, available bit rate (ABR), signal to noise ratio (SNR), bit error rate (BER) and achievable throughput) of available networks in heterogeneous environment to perform a network selection. Then calculates the multi objective function Network Selection Decision Function (NSDF) based on observed physical layer metrics.

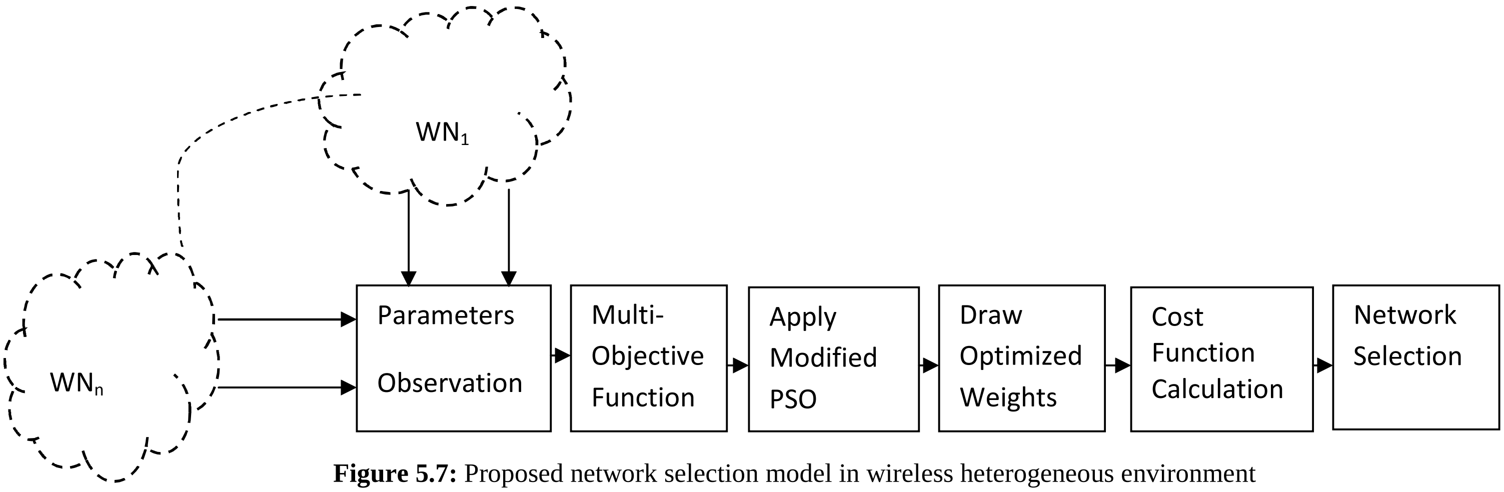


Figure 5.7: Proposed network selection model in wireless heterogeneous environment

The relative weights of each network selection metric are dynamic to several available wireless networks. Dynamic weights relative to selection metrics are optimized by using modified PSO. Cost function is calculated based on observed physical layer metrics and relative optimized weights. The network having greater cost function value is selected as the Optimum network (ON) in the given heterogeneous environment while maintaining QoS for multimedia services such as audio streaming, geographical mapping etc.

5.3.1. System model: In this section, we introduce network model of proposed network selection algorithm. For simplicity, we consider a heterogeneous wireless network consisting of EDGE and UMTS cellular networks as shown in Fig. 5.8. It is assumed that a user is traveling at a constant speed in a straight line and MS may move from the cell which is served by base station 'BS_g (EDGE)', towards another with 'BS_u (UMTS)' at constant speed along a straight line and vice versa. Where, 'D' is the distance between the two base stations. MS samples the pilot signal strength at regular distance intervals as in Eq. (5.1)

Selection metrics of cellular networks in heterogeneous environment viz. averaged RSS, outage probability have been already discussed in section 5.2.1, whereas available bit rate, signal to noise ratio, bit error rate and achievable throughput are discussed as follows:

Available bit rate is derived from Shannon Channel Capacity formula defined in Eq. (5.16). It depends on the channel bandwidth (BW) and SNR of cellular networks present in heterogeneous environment [195].

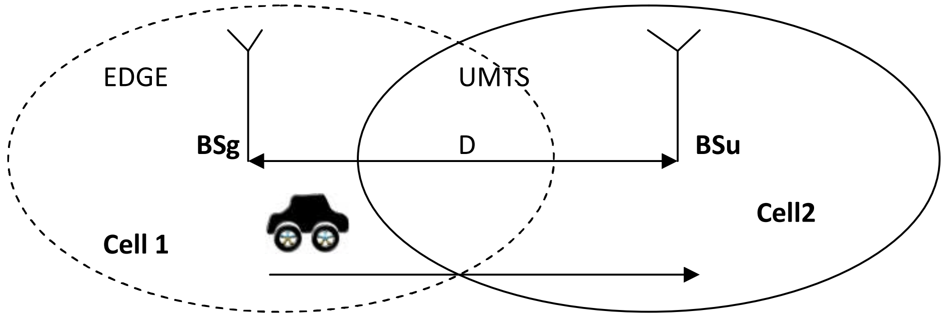


Figure 5.8: Heterogeneous wireless network model

$$C = BW \times log_2(1 + SNR) \tag{5.16}$$

ABR of cellular networks present in heterogeneous environment is calculated by using Eq. (5.17).

$$\text{ABR}_\text{i} = BW_i \times log_2(1 + SNR_i) \qquad \text{i=1, 2} \tag{5.17}$$

Where, SNR is the ratio of the transmitted information power to the noise power in the received signal. It is measured in dB (decibels). It is calculated by using Eq. (5.18).

$$SNR_i = \gamma_i = \frac{E_b}{N_0} \qquad \text{i=1, 2} \tag{5.18}$$

Here E_b is the received energy per bit and N_0 is noise power of the channel. The channel adds white noise with power spectral density N_0 watts/Hz and the signal arrives at the receiver at a power level of P watts [253].

Achievable throughput is another important selection metric of proposed network selection model. It is the amount of data moved successfully from one place to another in a given time period [253]. It is measured in bits per second (bit/s or bps). It is affected by the channel environment such as the distance between the transmitter and the receiver, noise, the fading state of the channel and interference power characteristics, packet size, transmission rate and number of overhead bits in each packet, the modulation technique, and the channel conditions. Achievable throughput is calculated by using Eq. (5.19)

$$T_i = \frac{\text{L} - \text{C}}{\text{L}} \times \text{R}_\text{i} \times (1 - \text{BER}_\text{i}(\gamma_\text{i}))^\text{L} \qquad \text{i=1, 2} \tag{5.19}$$

Where L is, length of each packet in bits, L is a combination of a payload (K bits) and overhead (C bits). C bits are equal to cyclic redundancy check bits. K=L-C. R is data rate and BER is the probability of bit error rate of cellular network present in heterogeneous environment. Probability of bit error rate is calculated by using Eq. (5.20) which depends upon signal to noise ratio.

$$\mathrm{BER_i}(\gamma_\mathrm{i}) = \frac{1}{2}\, e^{\frac{\gamma_i}{2}} \tag{5.20}$$

Probability of bit error rate defined in Eq. (5.20) is for non-coherent FSK in a white Gaussian noise [253].

For numerical computation, the typical values of system parameters falling in the range of practical interest have been taken as shown in Table 5.2.

Path loss exponent is lower in EDGE cell, resulting in moderate variation of signal strength with respect to distance as compared to UMTS cell.

Table 5.2: System parameters for simulation model

S.No.	**System Parameters**	**Value**
1.	Radius of EDGE (R_g)	1,000 m
2.	Radius of UMTS (R_u)	500 m
3.	Path loss exponent of EDGE (γ_g)	3.0
4.	Path loss exponent of UMTS (γ_u)	3.4
5.	Standard deviation of shadow fading σ_s	8 dB
6.	Sampling distance (d_s)	1 m
7.	Channel Bandwidth of EDGE network	200 KHz
8.	Channel Bandwidth of UMTS network	5 MHz

5.3.2. Proposed network selection criteria: The proposed network selection model devised a Multiple Attribute Decision Making (MADM) function which evaluates a set of cellular networks in heterogeneous environment. As discussed in earlier section, physical layer metrics are used to perform the network selection. NSDF is defined by using these metrics. The NSDF is an objective function that measures quality of each network at every location while moving from one network to another network. The NSDF is triggered if a new service request is made or a user changes preferences or the MS detects the availability of a new network or there is severe signal degradation or complete signal loss of the current radio link. NSDF is calculated by using Eq. (5.21) for cellular networks present in heterogeneous environment.

$$\mathrm{NSDF(i)} = \mathrm{RSS_i} \times \mathrm{W_{i1}} + \mathrm{ABR_i} \times \mathrm{W_{i2}} + \mathrm{SNR_i} \times \mathrm{W_{i3}} + \mathrm{Throu_i} \times \mathrm{W_{i4}} + \mathrm{Outage\ Prob_i} \times \mathrm{W_{i5}} + \mathrm{BER_i} \times \mathrm{W_{i6}} \quad (5.21)$$

where RSS_i, ABR_i, SNR_i, $Throu_i$ metrics are needed to be maximized and Outage $Prob_i$ and BER_i metrics are needed to be minimized for the always best connection (ABC) in cellular heterogeneous environment as defined in Eq.5.22

$$\mathrm{NSDF(i)} = \text{Maximize } (\mathrm{RSS_i} \times \mathrm{W_{i1}} + \mathrm{ABR_i} \times \mathrm{W_{i2}} + \mathrm{SNR_i} \times \mathrm{W_{i3}} + \mathrm{Throu_i} \times \mathrm{W_{i4}}) + \text{Minimize } (\mathrm{Outage\ Prob_i} \times \mathrm{W_{i5}} + \mathrm{BER_i} \times \mathrm{W_{i6}}) \quad (5.22)$$

W_{i1}, W_{i2}, W_{i3}, W_{i4}, W_{i5} and W_{i6} are dynamic metric weights of respective cellular network in heterogeneous environment. These dynamic weights are determined as follows:

$$\mathrm{W_{i1}} + \mathrm{W_{i2}} + \mathrm{W_{i3}} + \mathrm{W_{i4}} + \mathrm{W_{i5}} + \mathrm{W_{i6}} = 1 \quad (5.23)$$

Each dynamic weight is proportional to the significance of a metric to the network selection decision. The larger the weight of a specific metric, the more important that metric is to the user and vice versa. PSO algorithm is used to optimize the dynamic weights (W_1 to W_6) of proposed network selection algorithm by considering objective function defined in Eq. (5.22). The computation time constraint of multi objective PSO algorithm is relatively low and eventually conforms to the multimedia time requirement for reliable communication over wireless network. Several algorithms related to PSO have been proposed in the literature [254-261]. When using PSO, it is possible for the magnitude of the velocities to become very large. Two methods were developed for controlling the growth of velocities. First is to dynamically adjust the inertia factor and second is to use constriction coefficient. So to improve the inertia and convergence of the particle over time, a variant of PSO called as

Modified PSO [261] is used, where inertia factor (ω) and constriction coefficient (δ) have been introduced in the velocity update equation respectively.

A large inertia weight (ω) facilitates a global search while a small inertia weight facilitates a local search. By linearly decreasing the inertia weight from a relatively large value to a small value through the course of the PSO run gives the best PSO performance as compared to fixed inertia weight settings. Inertia factor (ω) is multiplied with velocity of particle at n^{th} position to obtain modified velocity update Eq. (5.24). ω is preliminary set to 1.0 and is gradually diminish over time.

$$V_{n+1} = \omega \times V_n + C_1 \times r_1 \times (P_{best,n} - Currentposition_n) + C_2 \times r_2 \times (G_{best,n} - Currentposition_n) \tag{5.24}$$

Constriction coefficient is multiplied with the whole right hand side of the velocity update equation. The modified velocity update Eq. (5.25) in context of convergence is obtained by

$$V_{n+1} = \delta \times \{\omega \times V_n + C_1 \times r_1 \times (P_{best,n} - Currentposition_n) + C_2 \times r_2 \times (G_{best,n} - Currentposition_n)\} \tag{5.25}$$

Where the constriction coefficient (δ) is given in (5.26)

$$\delta = \frac{2}{|2 - C - \sqrt{C^2 - 4C}|} \quad , \; C_1 + C_2 = C > 4 \tag{5.26}$$

Here C1 and C2 are the acceleration coefficients and the values are taken as 2 for easy convergence.

This optimization algorithm has been hybridized with decision making NSDF function and weighing function to achieve better solutions for network selection in heterogeneous environment. Cost function is calculated by using optimized dynamic weights and physical layer selection metrics for cellular networks present in heterogeneous environment by Eq. (5.27)

$$\text{Cost Function(i)} = RSS_i \times W_{1O} + ABR_i \times W_{2O} + SNR_i \times W_{3O} + Throu_i \times W_{4O} + \text{Outage Prob}_i \times W_{5O} + BER_i \times W_{6O} \tag{5.27}$$

Where, W_{1O} to W_{6O} are dynamic metric weights optimized by using modified PSO. The optimum wireless access network selection must satisfy Eq. (5.28):

Optimum Network (ON) = MAX (Cost Function (1), Cost Function (2)) i=1,2 (5.28)

Network having greater value of cost function is selected as the always best connected network or optimum access network in heterogeneous environment.

5.3.3. Performance evaluation: The performance of the network selection algorithm has been evaluated in a scenario when the MS moves with a constant velocity along a straight line trajectory between two BSs. It is evident from Fig 5.9 (a-f) that averaged RSS, ABR, SNR and achievable throughput gradually drops with increase in distance whereas BER and outage probability increases with distance. The above system performance is in close agreement with its desirable behavior as explained in section 5.3.1 which clearly indicates the suitability of modeled system for optimal network selection in cellular heterogeneous environment.

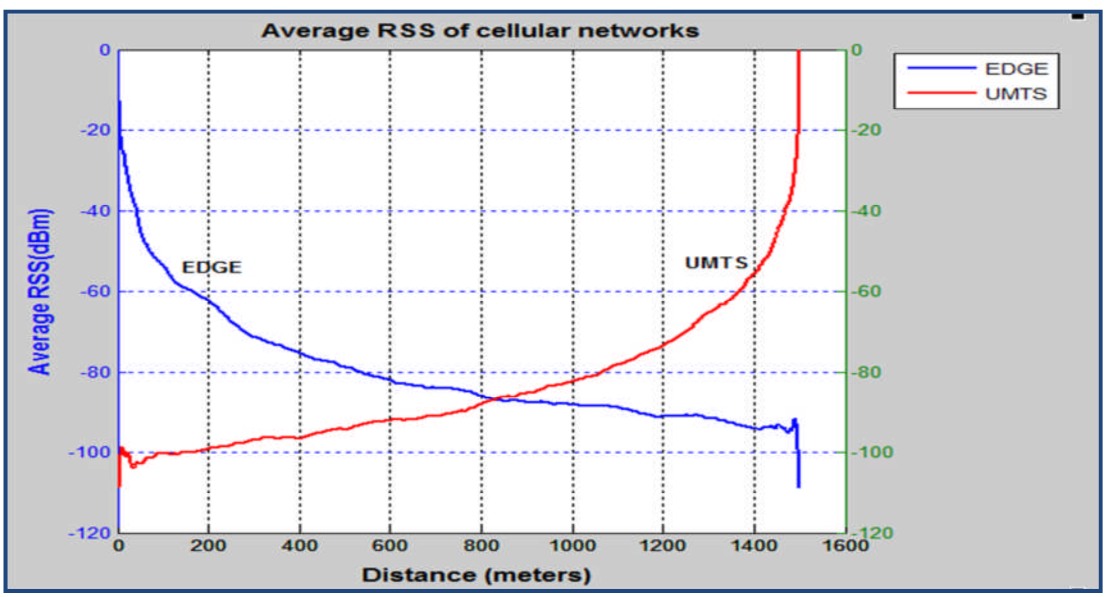


Figure 5.9: (a) Average RSS vs. Distance in cellular heterogeneous environment of EDGE and UMTS

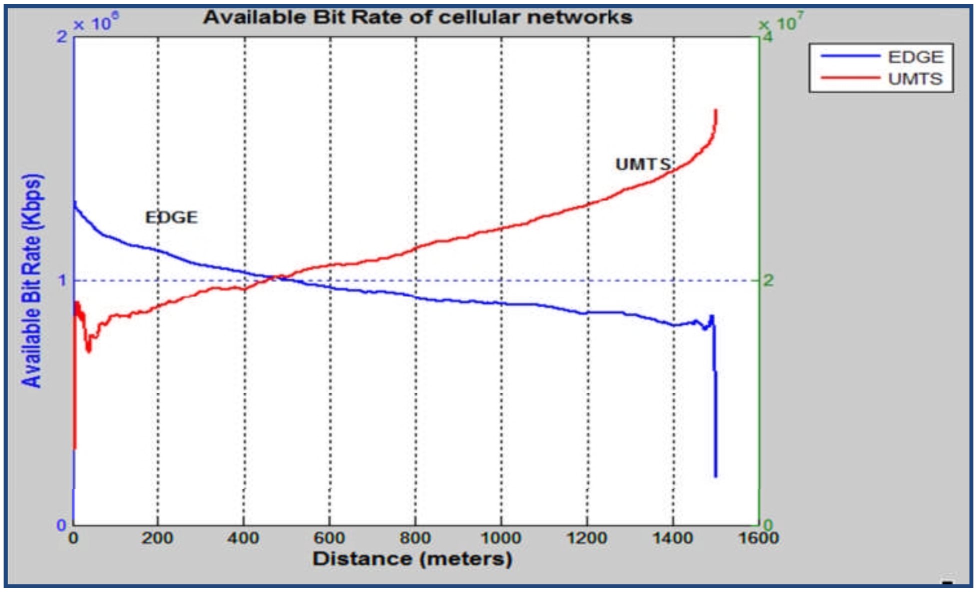


Figure 5.9: (b) Available Bit Rate (ABR) vs. Distance in cellular heterogeneous environment of EDGE and UMTS

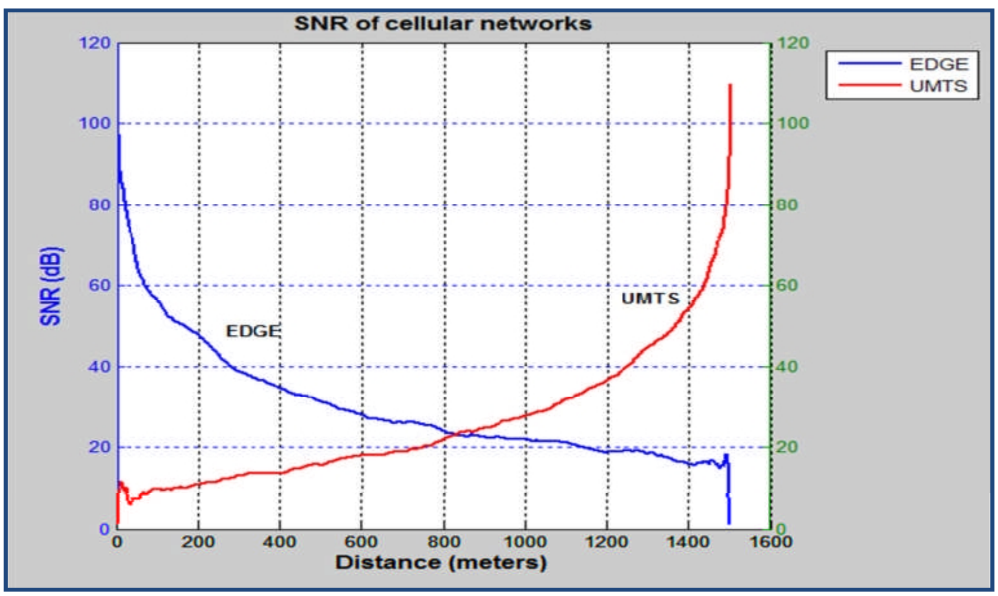


Figure 5.9: (c) SNR vs. Distance in cellular heterogeneous environment of EDGE and UMTS

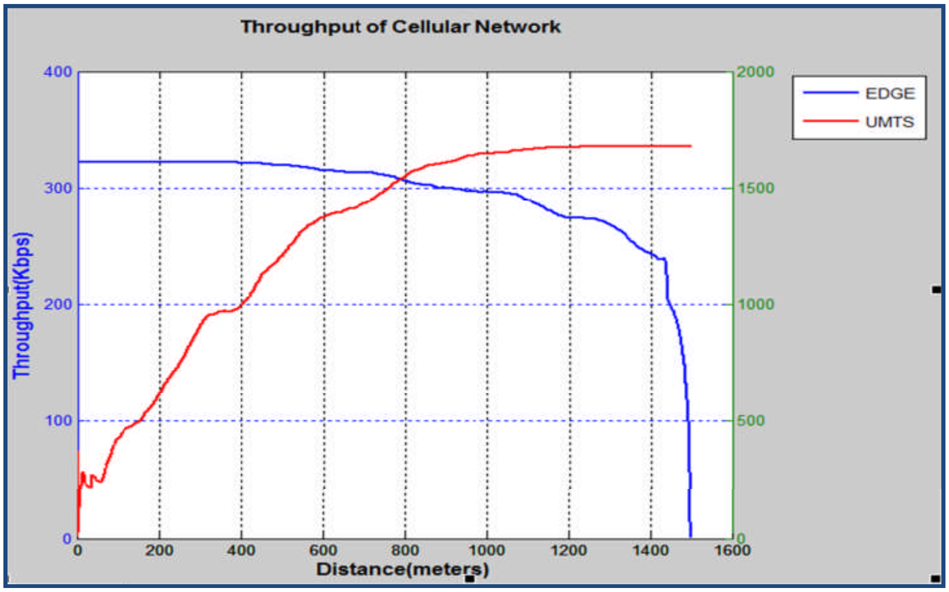


Figure 5.9: (d) Throughput vs. Distance in cellular heterogeneous environment of EDGE and UMTS

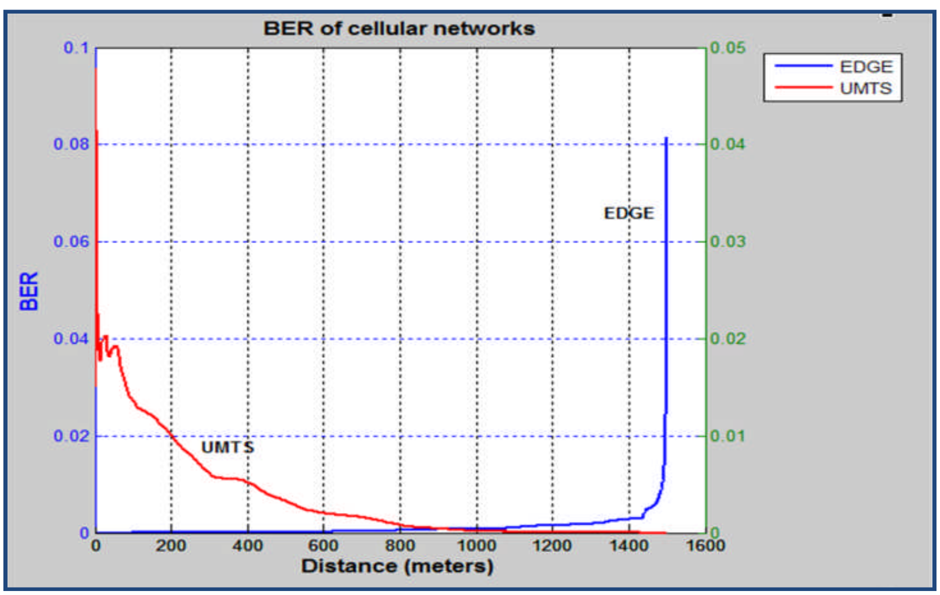


Figure 5.9: (e) BER vs. Distance in cellular heterogeneous environment of EDGE and UMTS

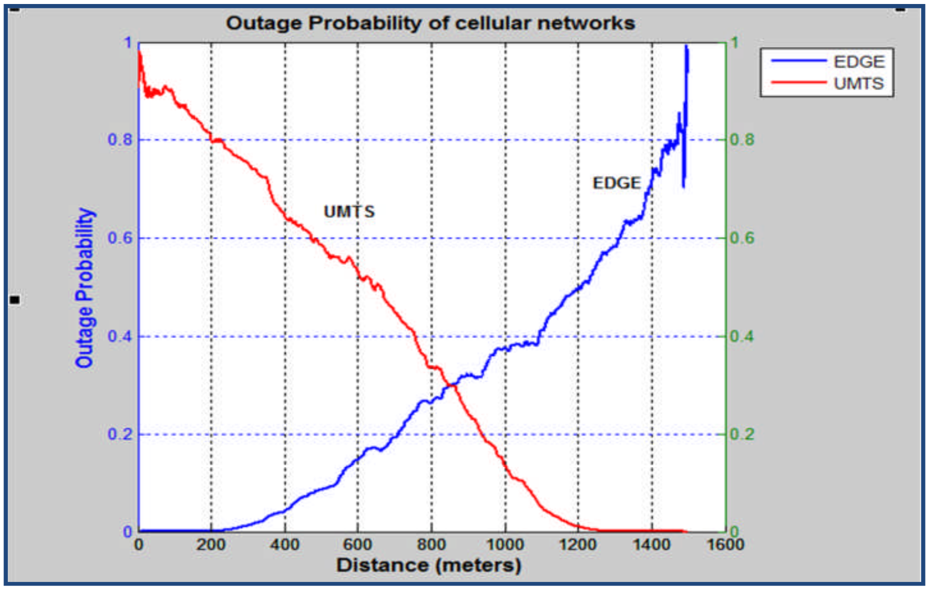
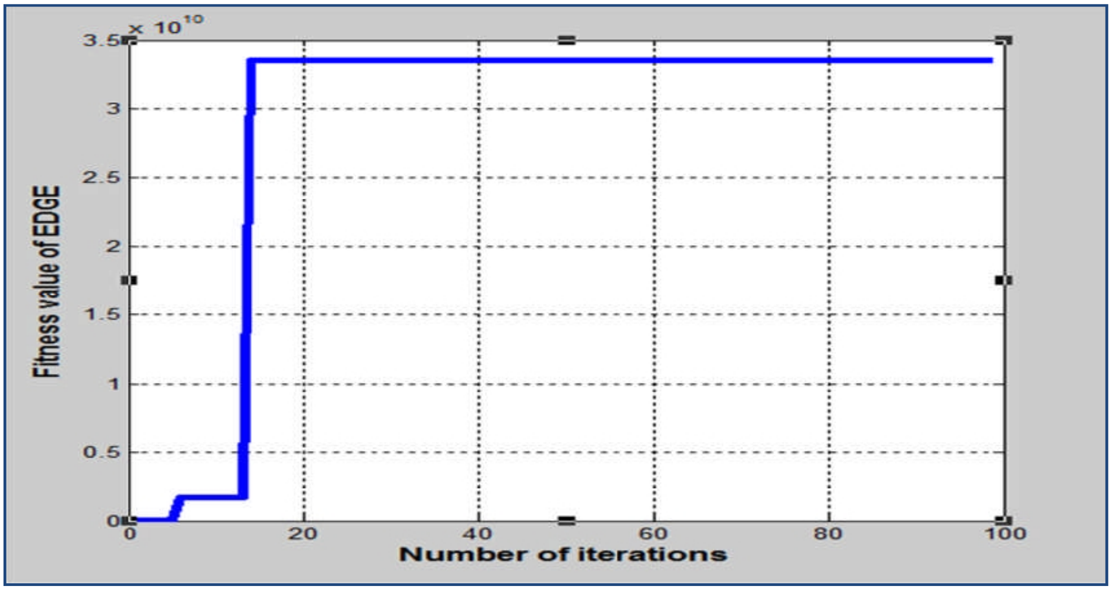


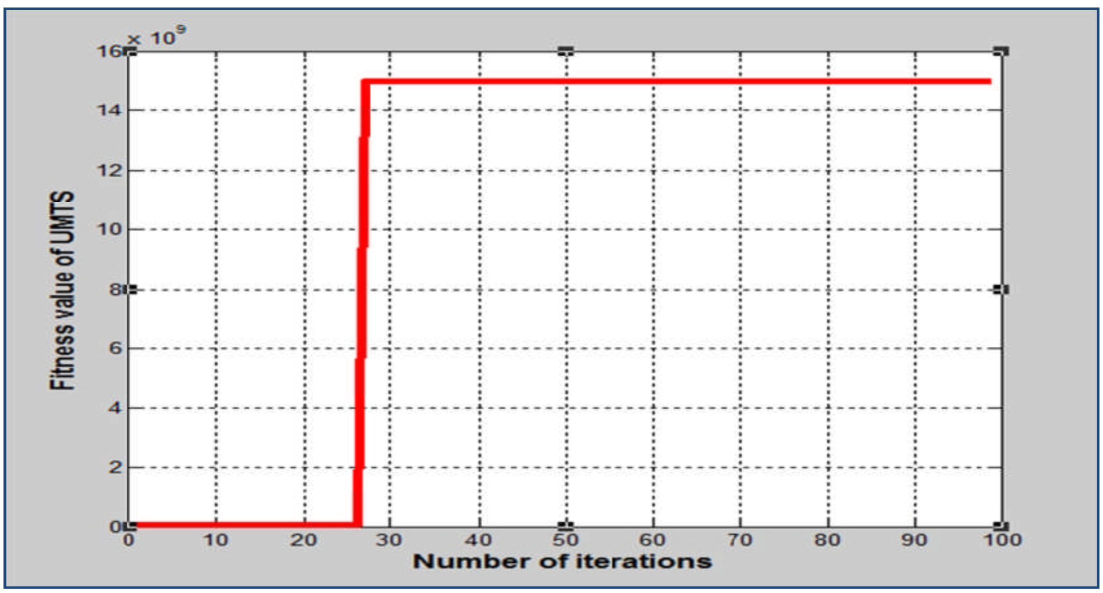
Figure 5.9: (f) Outage probability vs. Distance in cellular heterogeneous environment of EDGE and UMTS

Here, modified PSO has been implemented to optimize the dynamic weights upon locations of the user and its demands to the network to provide the best network selection. The impact of increasing the number of iterations on fitness value has been investigated in order to identify the number of iterations required to achieve optima and at the same time conform to the delay constraint for multimedia application. Iterations are varied from 10-100, which is based on the fact that no significant variation was observed after 100 successive iterations as shown in Fig 5.10 (a) & (b) for EDGE and UMTS cellular network respectively. Dynamic optimized weights after 100 iterations for EDGE are 0.4909, 0.0672, 0.0951, 0.1932, 0.0749 and 0.0786 whereas for UMTS network dynamic optimized weights are 0.3211, 0.1686, 0.0917, 0.0169, 0.0557 and 0.1032 for averaged RSS, ABR, throughput, SNR, BER and outage probability respectively.

Performance is evaluated on the basis of network selection rate parameter which is defined as the expected number of selections MS experiences while traversing a trajectory from one network to another. This performance measure represents switching load associated with the network selection process. The network selection rate is reduced to 1 by using dynamic weights optimized by PSO as compare to other existing network selection algorithm [21].



(a)



(b)

Figure 5.10: (a) Current fitness vs. Number of iterations of EDGE cellular network (b) Current fitness vs. Number of iterations of UMTS cellular network

Change of state only once between cellular heterogeneous networks with respect to distance based on proposed algorithm is shown in Fig 5.11. Reduction in network selection rate further reduces the signaling overhead on the MS as well as on the network.

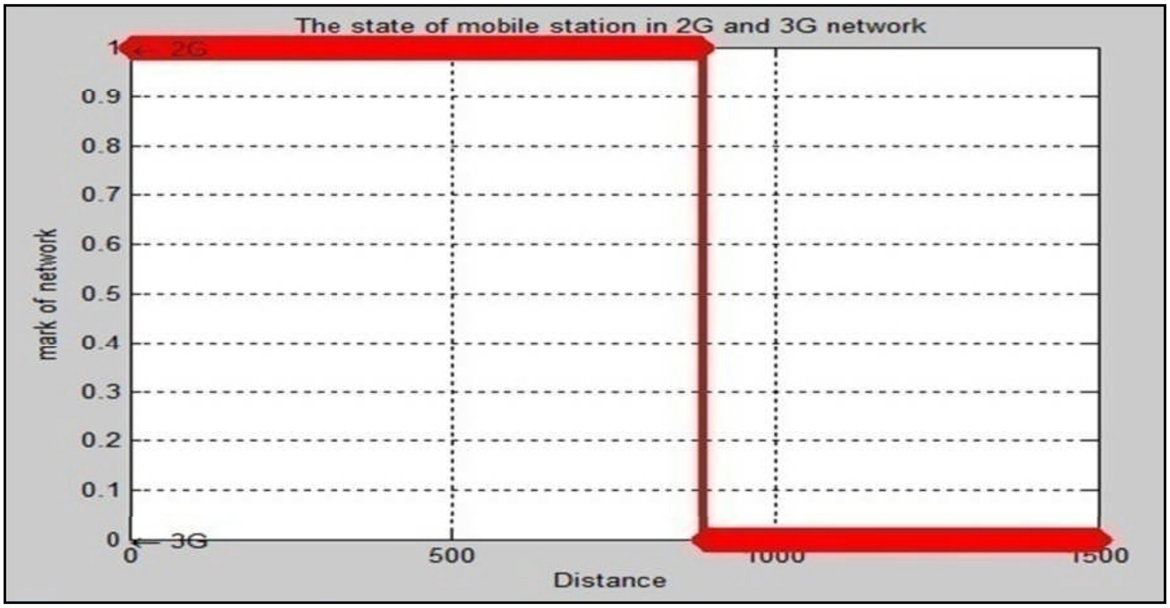


Figure 5.11: Network selection between EDGE and UMTS based on proposed algorithm.

The QoS attained for multimedia services by proposed algorithm is evaluated by means of a user satisfaction degree. To compute the user satisfaction, the modified sigmoid utility function is used as described in [262]. Based on the achievable throughput, the user satisfaction degree is given as

$$u_i(T_i) = 1 \qquad T_i > \eta_i$$

$$= \frac{\left(\frac{T_i - \eta_i^{min}}{0.5\eta_i - \eta_i^{min}}\right)^{\xi}}{1 + \left(\frac{T_i - \eta_i^{min}}{0.5\eta_i - \eta_i^{min}}\right)^{\xi}} \qquad \eta_i \geq T_i \geq \eta_i^{min}$$

$$= 0 \qquad otherwise \tag{5.29}$$

Where, η_i^{min} is the minimum acceptable bandwidth threshold of MS for multimedia services. The parameter ξ is the tuned steepness parameter which must be ≥ 2. A user will be completely satisfied if $u_i = 1$ or if user's achievable throughput is greater or equal to user's need i.e., $T_i \geq \eta_i$. User will be considered half satisfied if $u_i = 0.5$ or if user gets only a half amount of throughput that user needs for i.e., $T_i = 0.5\eta_i$. In this simulation, we assume that η_i^{min} = 64Kbps, η_i = 512Kbps and $\xi = 3$ for multimedia messaging, web browsing, interactive geographical mapping described in [263]. Fig 5.12 represents the utility function of MS of cellular networks in heterogeneous environment with respect to distance.

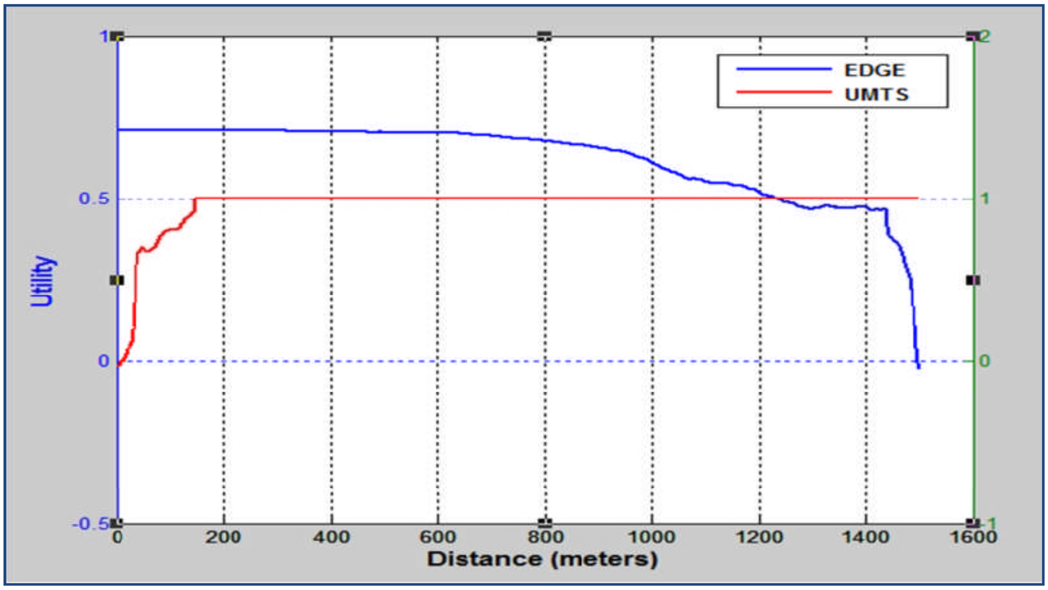


Figure 5.12: Utility function vs. distance in cellular heterogeneous environment of EDGE and UMTS

It is evident from Fig 5.12 that as the distance increases, utility value reduces in cellular networks. EDGE can never provide utility function equal to 1 because it can only support data rate up to 384 Kbps where the guaranteed bandwidth requirement of multimedia application is assumed to be 512 Kbps. UMTS network can approach utility function equal to 1 because it can support data rate up to 2 Mbps theoretically. Proposed algorithm maintains QoS while selecting ABC network in heterogeneous environment by keeping utility function atleast 0.5. Best QoS can be achieved when achievable throughput is greater than the guaranteed required bandwidth or utility function=1. When network selection is done by using proposed algorithm then utility function is always greater than or equal 0.5.

The proposed algorithm is applied as a part of the algorithm for initial selection of the access network as well as for vertical handover control. Simulation analysis and evaluation of the proposed algorithm with well-known mechanisms in heterogeneous wireless environment have shown that it outperforms other mechanisms, providing always best connected (ABC) network for MS.

5.4. Optimal network selection model for WiMAX and LTE networks

WiMAX (Worldwide Interoperability for Microwave Access) and LTE (Long Term Evolution) are expected to be the crucial technologies for broadband wireless access. Selection of the winner between these two most promising and contending technologies is a critical issue. Technological factors only partially contribute to determine the winner whereas the user satisfaction is the major concern. An appropriate network selection decisively depends on the user demand and satisfaction. Presently webs portal consist of high quality pictures, flash applications, animations and video telephony, multimedia messaging etc. User wants to watch streamed videos or play flash games on the Internet while they are on move. Services like Voice over Internet Protocol (VoIP) and the Internet Protocol television (IPTV) demand for higher transfer rates and better availability of mobile internet connections while user is on move. WiMAX and LTE are promising technologies to bring better availability, better transfer rates, lower latency, interference management [264] and much more to fulfill the needs of the users. The major objective is to develop an optimized weights based network selection criteria for multimedia applications in heterogeneous environment consisting of WiMAX and LTE technologies.

5.4.1. System model: A heterogeneous wireless network comprising of WiMAX and LTE networks has been modeled as shown in Fig 5.13 with an objective to select the most suitable network according to the user's demand.

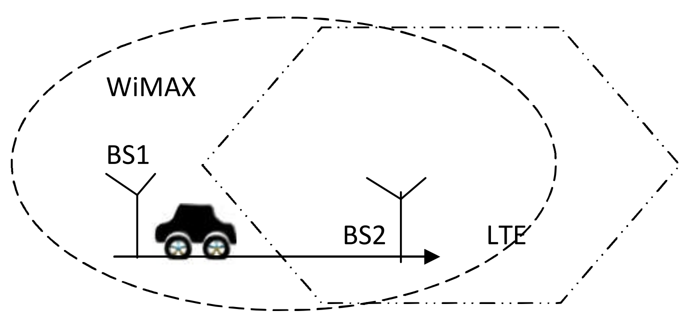


Figure 5.13: Heterogeneous environment comprising of WiMAX and LTE wireless networks

It is assumed that a user is traveling at a constant speed in a straight line and initially move from the cell served by base station 'BS_1 (WiMAX)', towards another with 'BS_2 (LTE)' located at distance 'D' from BS_1. Users sample the pilot signal strength at regular distance intervals as defined in Eq.5.1

Here, D is considered equal to1500 m. Both the base stations are assumed to be located and operating from the center of the respective cells. Also, it is considered that users have random motion in the region defined by 'D'. The physical layer parameters (RSS, ABR, SNR, Achievable throughput, and BER) of available wireless networks are calculated using Eqs. (5.16-5.20) as described in section 5.3.2 and Eq. (5.30) [265].

$$RSS_i = -174+(Si/Ni)-10\times \log_{10}(d) + 10\times \log_{10}(FS_i\times Nused_i/Nfft_i) + NF_i \qquad i = 1,2 \qquad (5.30)$$

Where, i=1, 2 represents WiMAX and LTE network respectively. RSS_i defines the received signal strength of available networks. RSS_i value at any instance of distance 'd' depends on signal to noise ratio (S/N), frequency (Fs), number of sub carrier used (Nused), FFT size (Nfft) and Noise Figure (NF). For simulation, the typical values of system parameters are chosen in the range of practical interest as shown in Table 5.3.

Table 5.3: System parameters for simulation model [265]

S.No.	System Parameters	WiMAX	LTE
1.	Channel Bandwidth (Scalable)	3.5 – 10 MHz	1.4 – 20 MHz
2.	Peak data rate	75 Mbps	100 Mbps
3.	Nused	192	1024
4.	Nfft	256	256
5.	NF	12 dB	12 dB
6.	SNR	5-21 dB	5-40dB
7.	F_S	2.5*1e+6	20*1e+6

5.4.2. Proposed network selection algorithm: Initially, consider that there are n numbers of users and satisfied users are null. Check availability of wireless networks. If number of available networks is more than one. Observe the physical layer parameters (RSS, ABR, SNR, Throughput and BER) of available networks. Calculate Selection Decision Function (SDF) function of available wireless networks using Eq. 5.31

$$SDF(i) = W_{ij} \times RSS_i + W_{ij} \times ABR_i + W_{ij} \times SNR_i + W_{ij} \times Throu_i + W_{ij} \times BER_i \quad (5.31)$$

Where, W_{ij} defines the relative weights to input parameters. i = 1, 2,…….., N according to available networks in heterogeneous environment and j = 1,2,…….M depends on the input parameters of available networks. Here, we consider N=2 and M=5. All relative weights must satisfy Eq. 5.32 such that

$$W_{i1} + W_{i2} + W_{i3} + W_{i4} + W_{i5} = 1 \quad (5.32)$$

Optimize the relative weights of input parameters (RSS, ABR, SNR, Throughput and BER) using modified particle swarm optimization (PSO) [266] with the objective function as

$$\text{Objective Function} = \text{Maximize } (w_1 (i) \times RSS (i) + w_2 (i) \times ABR (i) + w_3 (i) \times SNR(i) + w_4 (i) \times throu (i)) + \text{Minimize } (w_5(i) \times BER (i)) \quad (5.33)$$

Calculate cost functions of both the networks based on input parameters of available networks and the optimized weights using Eq. 5.34 and 5.35. Here subscript 'o' used to represent optimized weights of respective wireless networks.

$$\text{Cost Fun1} = w_{11o} \times RSS_1 + w_{12o} \times ABR_1 + w_{13o} \times SNR_1 + w_{14o} \times throu_1 + w_{15o} \times BER_1 \quad (5.34)$$

$$\text{Cost Fun2} = w_{21o} \times RSS_2 + w_{22o} \times ABR_2 + w_{23o} \times SNR_2 + w_{24o} \times throu_2 + w_{25o} \times BER_2 \quad (5.35)$$

To get optimal network selection between available wireless networks, compare their cost functions. Network having high cost function value is considered as optimum network for user connectivity. Number of satisfied users is calculated according to the completion of their respective demand from the selected network. If user runs multimedia applications then available bit rate and throughput are necessary requirements while for the user in far area from the transmitter or in NLOS (Non Light of Sight) region, RSS and SNR are considered as deterministic factors. By using cost functions of available wireless networks the number of satisfied users is calculated depending upon their application prerequisite as given below:

{

If (RSS_1 > RSS_2 or ABR_1>ABR_2 or SNR_1 > SNR_2 or $Throu_1$ > $Throu_2$ or BER_1>BER_2)

then (calculate Z = Cost Fun_1/Cost Fun_2)

else (Z = Cost Fun_2/Cost Fun_1)

if (Z>1)

then calculate satisfied users (λ)

Optimize satisfied users (λ) using modified PSO

}

The maximum number of satisfied users is optimized using modified PSO [266]. The total number of users considered in system model are 1500. The number of satisfied users is calculated depending upon their fulfillment of requirement according to respective application they prevail among all users in the scenario. The flow graph of proposed algorithm for network selection in heterogeneous environment of WiMAX and LTE is shown in Fig 5.14.

5.4.3 Performance evaluation of proposed algorithm: The performance of the proposed network selection algorithm has been evaluated in heterogeneous environment which consists of WiMAX and LTE networks.

MS can move along a straight line and randomly also with a constant speed between two BSs. The impact of movement path is evaluated considering both random and straight line trajectory of single MS while in motion. Number of network selections with respect to distance is shown in Fig 5.15. MS experiences higher number of selections while traversing a random trajectory as compared to straight line movement. It represents switching load associated with the network selection process.

On the implementation of the proposed algorithm, only one selection occurred across the cell boundary (ideal) for straight line motion of the user; however, multiple selections were recorded for random motion of the user when it crossed the cell boundaries repeatedly as shown in Fig 5.15 (a) and 5.15 (b)

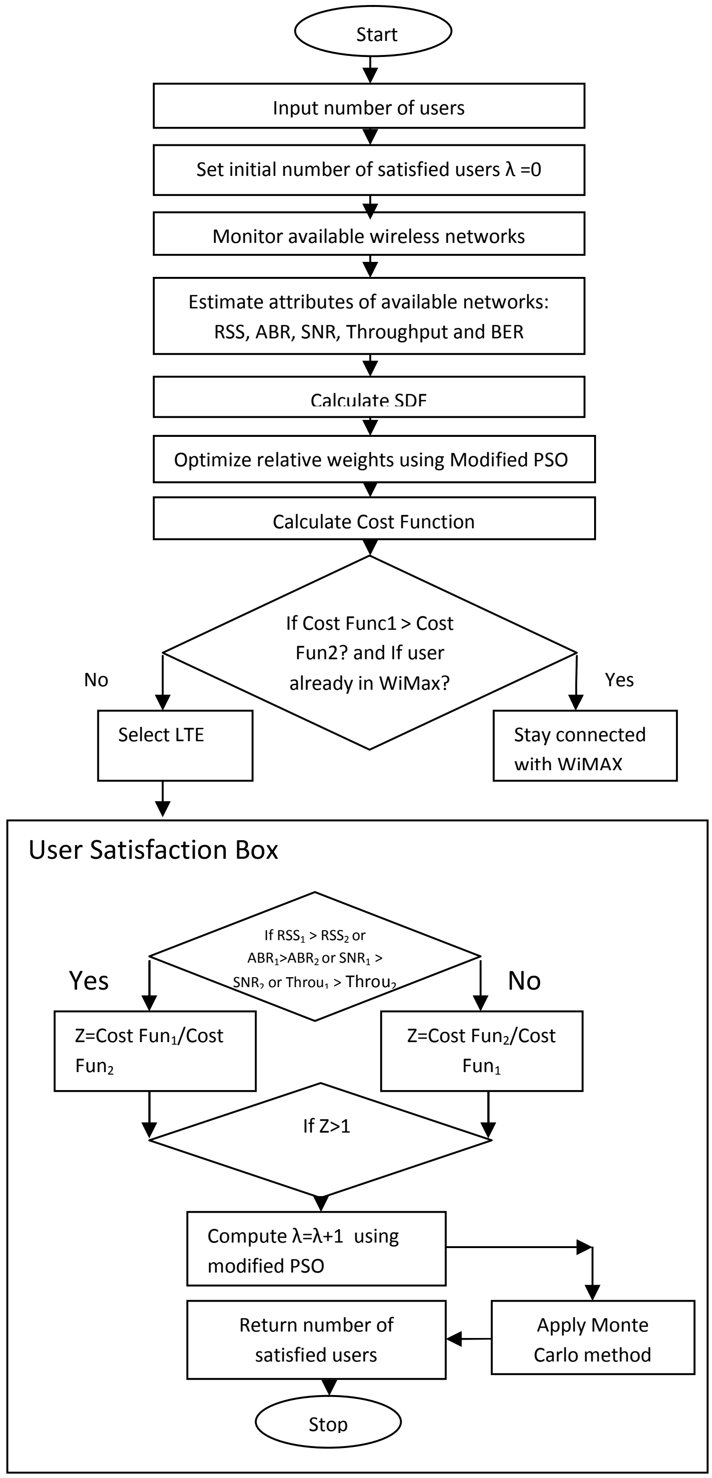
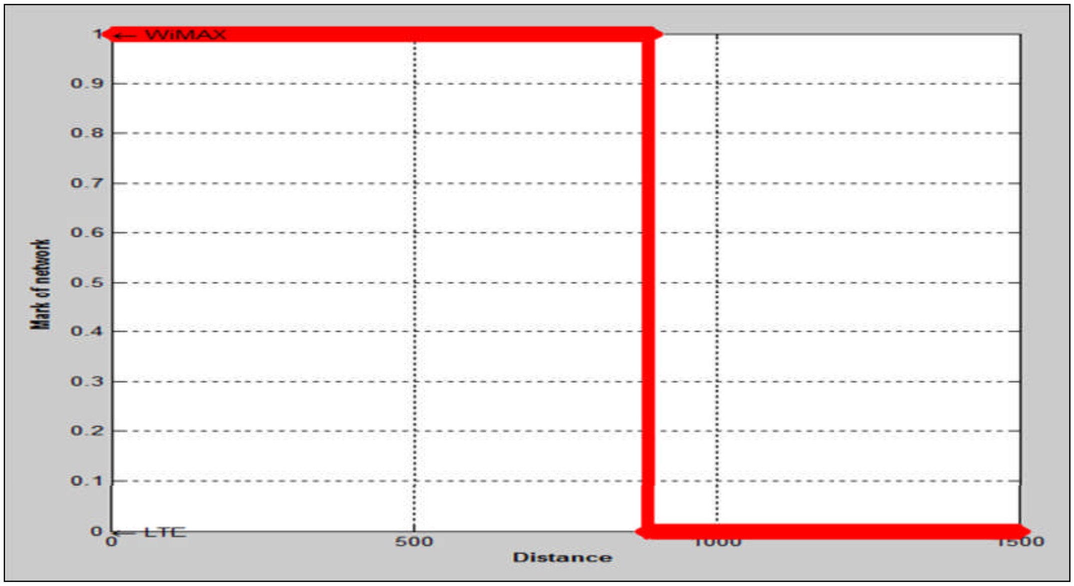
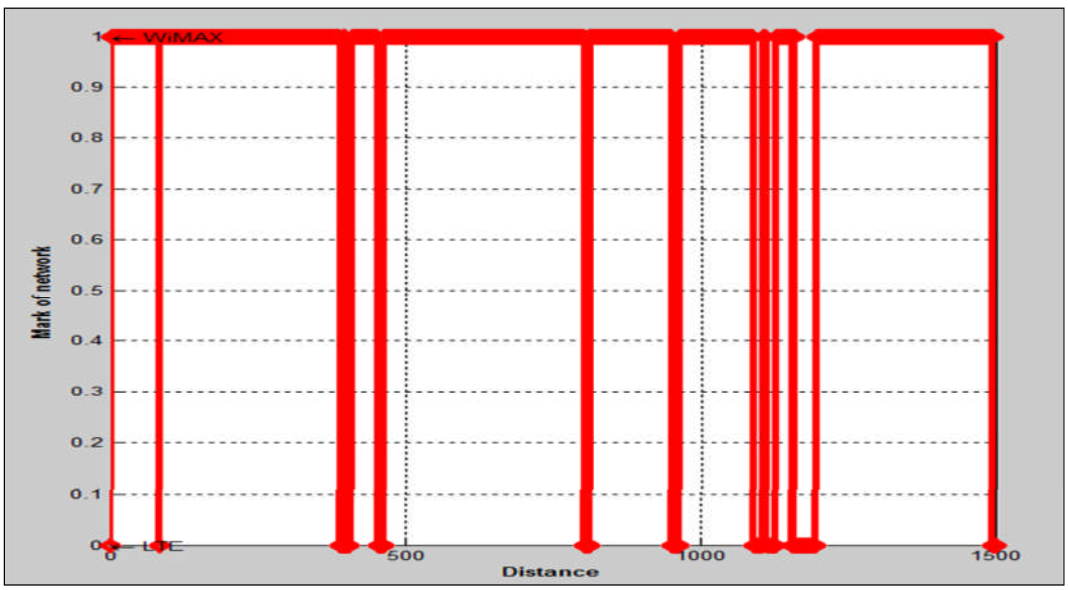


Figure 5.14: Flow diagram of proposed algorithm for network selection in heterogeneous environment of WiMAX and LTE with satisfied user



(a)



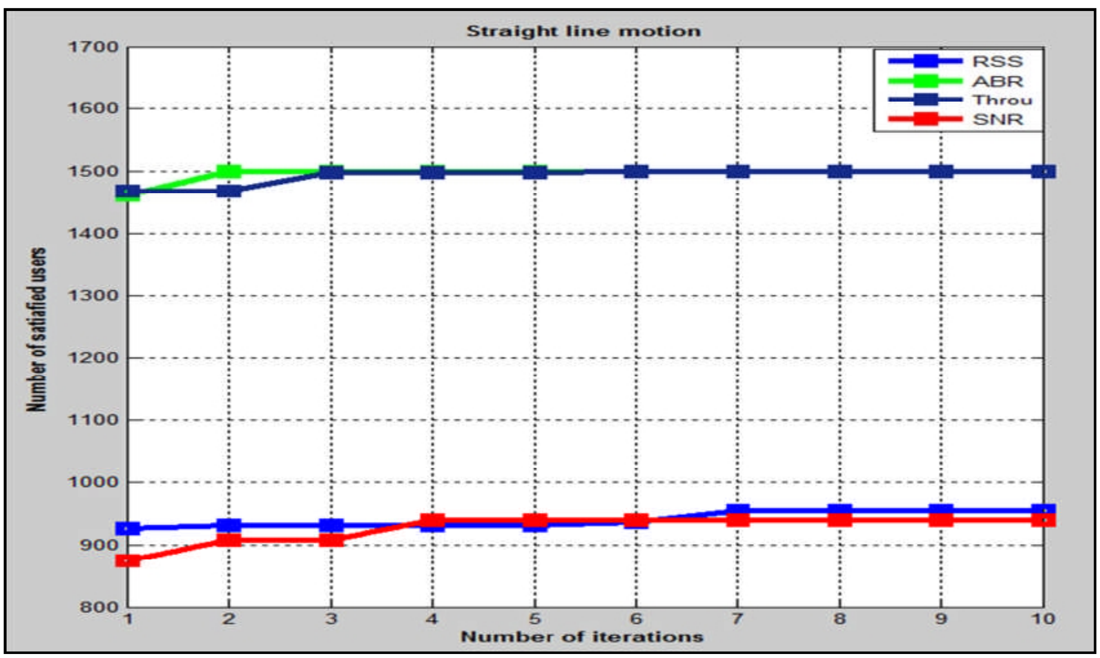
(b)

Figure 5.15: Number of network selections with respect to distance (m) **(a)** straight line movement **(b)** random movement

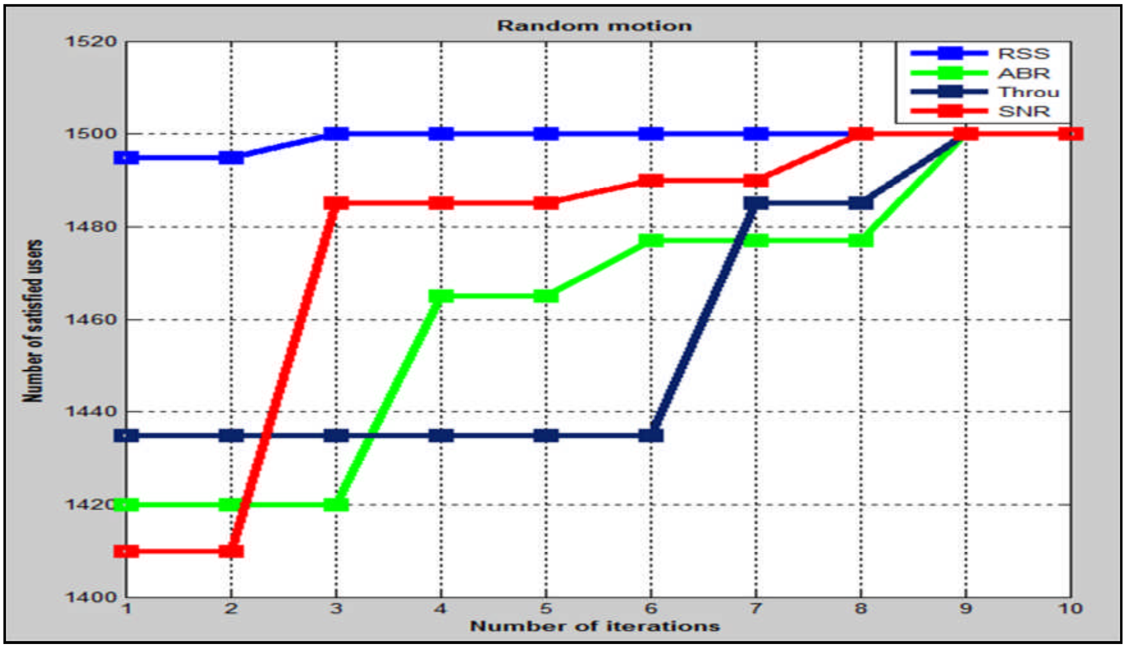
Here four types of services have been considered to analyze the impact of network selection on multimedia users in term of satisfied users. Each of the four service types is defined in terms of required attributes. Service type with lower data rate and high RSS requirement represents telephony services. Service with higher throughput requirement is considered as video streaming service, third service type is video conferencing, which requires higher available bit rate and online radio service by mobile user is modeled as fourth service type. Service types with their required range are tabulated in Table 5.4. According to the service type, number of satisfied users is shown in Fig 5.16 (a) and (b) for straight line and random motion respectively.

Table 5.4: Types of services availed by users [267-269]

S.No.	Service Type	Attribute (s)	Range
1.	Telephony services	RSS	(-75dB)
2.	Video conferencing	Available bit rate	(64 Kbps-4Mbps)
3.	Online Radio	SNR	(10 dB)
4.	Video streaming	Throughput	(1Mbps-1.5Mbps)



(a)



(b)

Figure 5.16: Number of satisfied users with **(a)** straight line motion **(b)** random motion

In order to ensure better accuracy, computations have also been carried out using Monte Carlo method defined in [270]. It facilitates statistical evaluation of random samples. Only one typical computations of satisfied users based on RSS as shown in Fig 5.17, whereas details for other services is tabulated in Table 5.5. Above results show that a user is attached to a network, which provides the best user satisfaction in term of the bit rate, SNR and throughput requirement for each service type.

Table 5.5: Satisfied users using Monte Carlo method

User's Motion Type	**Attributes**			
	RSS	**ABR**	**SNR**	**Throughput**
Straight Line	945	1465	935	1490
Random	1495	1440	1420	1485

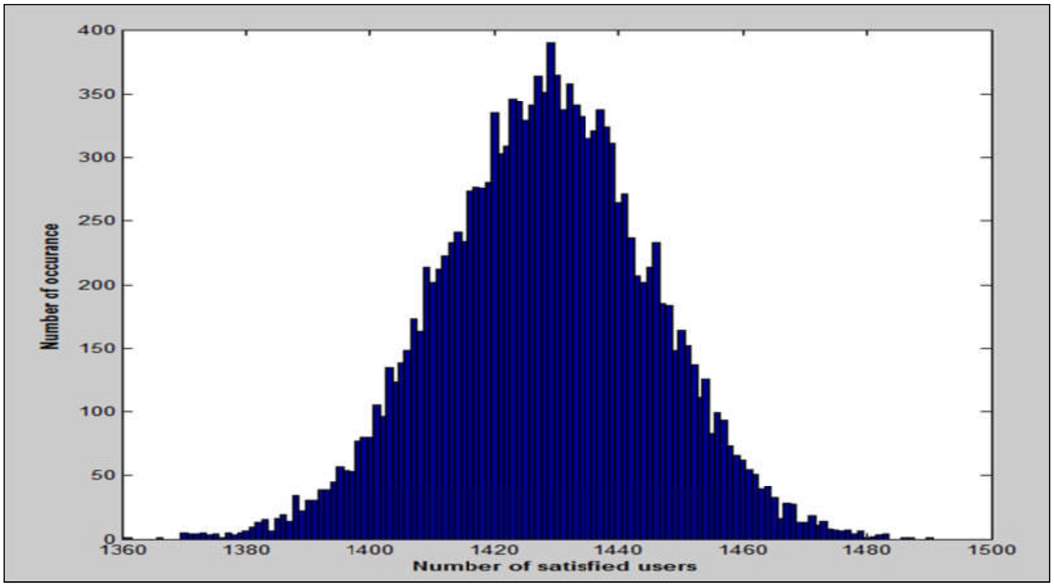


Figure 5.17: Number of satisfied users using Monte Carlo method

5.5. Summary

We proposed algorithms for network selection based on the link parameters. Network selection function (NSF) consists of averaged RSS, distance and outage probability parameters to select the optimum network between two different networks- GSM and UMTS. The predicted overlapped distance is utilized to make a network selection in order to minimize the probability of network selection failures or unnecessary selections from one cellular network to another. Network selection rate is computed for different values of T_{umts}, which is varied from -106 *to* $-74dBm$, while keeping $T_{gsm} = -88\ dBm$. For conventional method based on RSS only, the network selection rate equal to 6.299 is obtained at $T_{umts} = -94\ dBm$, while NSF algorithm based on distance, averaged RSS and outage probability yields network selection rate equal to 1.999. In another case, network selection rate is computed for different values of T_{gsm}, which is varied from -94 *to* $-72\ dBm$. Keeping $T_{umts} = -94\ dBm$, network selection was computed for different perspective of signal strength threshold T_{gsm}. At $T_{gsm} = -88$dBm, the network selection rate of conventional method was found to be 6.301 whereas it was observed only 2 for NSF based algorithm. Because of the overlapped region, the overhead on MS reduced significantly and outperformed the conventional algorithm. Significant reduction of 68% in network selection rate has been obtained with the application of proposed algorithm as compared to conventional method. In

NSF algorithm, network selection can be initiated within 653m to 1495m by setting T_{umts}= −74 to −106 dBm. As such, under proposed NSF algorithm, network selection can be occurred at 1002m by setting T_{umts} = −94 dBm as per selection conditions in an overlapped area. Under proposed NSF algorithm, network selection can be initiated from 886m to 1139m whereas it ranges from 781m to 1123m for conventional algorithm at T_{gsm}= −72 to −94 dBm. In analogy, by conventional algorithm, network selection can take place at 991m by setting T_{gsm} equal to −92dBm whereas, network selection can take place between 907m and 1022m by setting T_{gsm} from −88dBm to −92 dBm in proposed algorithm. Due to observed reduction in link quality from BS_g minimum T_{gsm} value has been fixed at −88dBm. It is reported here that the proposed algorithm accomplished the network selection decision in accordance with the application requirements and also kept the connection dynamic during handover by engaging make-before-break approach and thus facilitated adaptive soft handover. A possible improvement to the scheme is to periodically sample the RSS, recalculate and refine the estimations for *v* to improve the performance, and eliminate the assumption that the MS's speed remains fixed inside the heterogeneous wireless network. For higher speeds, proposed algorithm yields lower probability of network selection failures and unnecessary selections than the other existing methods. In addition to above, another network selection algorithm has been proposed utilizing signal strength, available bit rate, signal to noise ratio, achievable throughput, bit error rate and outage probability metrics as coefficient of cost function NSDF for network selection. The selection metrics are hybridized with PSO for relative dynamic weight optimization. The NSDF supported algorithm is implemented in a typical heterogeneous environment of EDGE (2.5G) and UMTS (3G). It is based on dynamic metric weights optimized by using modified PSO which resulted in significant reduction of the network selection rate, computational complexity and time. The network selection rate is reduced to unity as compared to other existing network selection algorithm. It further maintains QoS while selecting ABC network in heterogeneous environment by keeping utility function at least 0.5. Best QoS can be achieved when achievable throughput is greater than guaranteed required bandwidth or utility function equal to 1. When network selection is done by using NSDF supported algorithm then utility function is always greater than or equal 0.5. It is extremely useful and applicable in supporting multimedia applications over wireless environment due its high convergence capability and simplicity.

In continuation, another network selection algorithm on same platform for a heterogeneous environment consisting of WiMAX and LTE standard is proposed. It is based on received signal strength, signal to noise ratio, available bit rate, achievable throughput and bit error rate. Relative weights of the decision making attributes are optimized by employing particle swarm optimization approach. Satisfaction decision function (SDF) utilizes dynamic optimized weights to select optimal network in heterogeneous environment of cellular networks. The number of satisfied users is calculated by wireless network selected. It is further optimized by modified PSO and affirmed by Monte Carlo method. It is observed that network selection rate varies in accordance with user's motion. It is reported here that the number of network selections increases when users move randomly in heterogeneous coverage area. Performance of SDF based algorithm has been evaluated in terms of satisfied users. It is concluded that SDF based algorithm yields 50% better performance than existing techniques/algorithms.

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1. Summary

In a highly integrated ubiquitous heterogeneous wireless environment, network selection which can fulfill end-users' service requests while keeping their overall satisfaction at a very high level is vital. Incorrect selection can lead to undesirable conditions such as weak QoS, unsatisfied users, dropped and/or blocked calls, network congestion, and wastage of valuable network resources. Conventional schemes trigger the network selection process based on a single metric such as RSS. These schemes are not efficient as these do not take into consideration the network conditions, user preferences, traffic characteristics and other important system metrics.

The focus of this research work is on the design and implementation of schemes that can perform efficient network selection in heterogeneous wireless networks. The main objective of the developed schemes is to minimize the number of unnecessary network selections and network selection failures while on move, with increased end-users' satisfaction levels for multimedia applications. We have proposed different algorithms based on QoS, link parameters and other dynamic attributes to achieve this objective.

First of all, a case study has been carried out to select best suitable network in a heterogeneous environment consisting of UMTS, WLAN, GPRS, and WiMAX. Mathematical model TOPSIS and MADM algorithm based on AHP has been applied for network selection considering streaming to be a generic service. It was observed that WiMAX network has the highest Preference Value (P = 0.9565) and thus selected the best among all available networks in heterogeneous environment. It has been observed that different criteria for different generic services and conditions influences the network selection decision based on performance, cost and accessibility ratings. The main constraint observed in this study was the choice of weights of attributes of various networks. In order to resolve this issue a new network selection algorithm based on weight estimation of the representative set of the network attributes has been proposed using entropy and TOPSIS approach. The proposed model has been effectively implemented to select the desired network in a considered heterogeneous environment employing triple-play services. The results show that the proposed algorithm can select the best available network in heterogeneous environments based on user preferences and/or service requirements. For voice service, the user's preference lies in minimum delay and GPRS was found to be optimal network based on BW, L and CB, even though the delay in the case of UMTS is observed to be is marginally low. In case of video services, bandwidth is the dominant parameter and WiMAX emerged as an optimal access network for video services. The user demands for data services at lower data cost and from our investigations it was observed that WLAN has the lowest data transfer cost. However, when all the services viz. voice, video and data were considered together, UMTS yielded the optimal response resulting in better QoS.

In addition to above, a novel method has been proposed that takes into consideration user preferences (requested data rate, velocity, tolerable data loss), network conditions (available capacity, coverage, expected data loss due to network overloading/network selection delay) and QoS (network selection rate, RSS, delay, jitter) in order to select the optimal network between WiMAX and 3G and achieves the best balance between user and network performance for different real time and non real time applications. In the RT traffic (such as VoIP) case, the proposed scheme performs better as compared to other two schemes (RSS based scheme, Hungry scheme) by at least 10% in terms of the data loss caused by network selection delays and overloaded networks. In NRT traffic (such as web browsing) case, the performance impact by the frequent network selection is less critical than in RT traffic case. The performance of system in terms of throughput against the other network selection schemes was found to be better in NRT traffic. It yielded better performance by reducing the data loss and enhanced the throughput while considering 250 users. This scheme effectively maintained equilibrium between the user's preferences, services requirements and networks conditions. The solution is realistic and not very complex to implement on mobile users and other network elements.

We have proposed a novel network selection algorithm capable of adapting to prevailing network conditions in heterogeneous environment of 3G & WLAN networks, 3G & WiMAX and WLAN & WiMAX in real time based on available bandwidth estimation. We utilized a bootstrap approximation based technique to estimate available bandwidth and compared it with hidden Markov model based estimation to verify its precision. It was implemented for the selection of the best suitable network in the heterogeneous environment consisting of 2G & 3G and 2G, 3G & WLAN standards based wireless networks. The proposed algorithm performed well in terms of estimation error (less than 15%), overhead (varied from 0.45% to 72.91%) and reliability (approx. 99%) with respect to existing techniques in heterogeneous environment of 2G and 3G. ABW estimation technique based on bootstrap approximation has been implemented for proposed network selection which outperformed the existing techniques in terms of estimation error (less than 20%), overhead (varied from 0.03% to 83%) and reliability (approx. 99%) in heterogeneous environment comprising of 2G, 3G and WLAN. The proposed algorithm's ABW estimation proved to be more efficient in comparison to existing on the basis of relative accuracy (estimation error), overhead, estimation time and reliability which further validates the feasibility of proposed algorithm for network selection in heterogeneous environment of 2G and 3G.

We further proposed algorithms for network selection based on the link parameters. Network selection function consists of averaged RSS, distance and outage probability parameters to select the optimum network between two different networks- GSM and UMTS. The predicted overlapped distance has been utilized to make a network selection in order to minimize the probability of network selection failures or unnecessary selections from one cellular network to another. For conventional method based on RSS only, the network selection rate reported is 6.299 at $T_{umts} = -94\ dBm$, while NSF algorithm based on distance, averaged RSS and outage probability yielded network selection rate of 1.999. In another case, network selection rate has been computed for different values of T_{gsm}, varying from -94 to $-72\ dBm$. At $T_{gsm} = -88$dBm, the network selection rate of conventional method was found to be 6.301 whereas it was observed only 2 for NSF based algorithm. Because of the overlapped region, the overhead on MS reduced significantly and outperformed the conventional algorithm. Significant reduction of 68% in network selection rate and significant reduction in call dropping probability has been obtained with the application of proposed algorithm as compared to conventional method. It is reported here that the proposed algorithm accomplished the network selection decision in accordance with the application requirements and also kept the connection dynamic during handover by engaging make-before-break approach and thus facilitated adaptive soft handover. For higher speeds, proposed algorithm yielded lower probability of network selection failures and unnecessary selections than the other existing methods. In addition to above, another network selection algorithm has been proposed utilizing signal strength, available bit rate, signal to noise ratio, achievable throughput, bit error rate and outage probability metrics as coefficient of cost function NSDF for network selection. The selection metrics are hybridized with PSO for relative dynamic weight optimization. The NSDF supported algorithm has been implemented in a typical heterogeneous environment of EDGE and UMTS. It resulted in significant reduction of the network selection rate, computational complexity and time. The network selection rate reduced to unity as compare to other existing network selection algorithm. Minimization of network selection rate while maintaining QoS for multimedia services was recorded which in turn reduced the overhead on the MS. It maintained QoS while selecting ABC network in heterogeneous environment by keeping utility function at least 0.5. It is found extremely useful and applicable in supporting multimedia applications over wireless environment due its high convergence capability and simplicity.

In continuation, another network selection algorithm on same platform for a heterogeneous environment consisting of WiMAX and LTE standard was proposed. It was observed that network selection rate varied in accordance with user's motion. The number of network selections increased when users moved randomly in heterogeneous coverage area. 1500 users have been considered in the proposed system model and performance of SDF based algorithm has been evaluated in terms of satisfied users. SDF based algorithm yielded 50% better performance than existing techniques/algorithms.

The proposed algorithms have potential for practical implementation in the wireless networks. These are simple and easy to implement at the user end and the network side as well. An important highlight of this research work is that the network access selection eventually not only benefits the end users but provide ubiquitous seamless communication with the help of various network operators available. This research work could help the wide deployment of network selection algorithms in future mobile terminals and end user equipments.

6.2 Future work

Different aspects of the proposed scheme can be further improved. Some of the future directions related to network selection in heterogeneous environment are outlined below:

• The network selection process is one aspect of an overall mobility framework to provide ubiquitous access to MSs moving in a heterogeneous wireless environment. The proposed network selection algorithm can be combined with other resource management tasks such as call admission control and power, and channel assignments to provide guaranteed and continued quality of service. A joint optimization of such an integrated system may result in an overall optimal performance with increased users' satisfaction.

• Optimization of the cost function based algorithms through the use of hybrid optimization techniques such as GA, ACO, fuzzy, neural or Bayesian networks could be undertaken.

• Detailed complexity analysis in terms of resources usage and load balancing to determine the feasibility of proposed schemes is another area for further study. As MS-battery consumption is critical in any MADM based scheme, a power efficient network selection scheme can be devised that can provide intelligent handoff decisions.

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