A Study of Vertical Handoff Decision Strategies in Heterogeneous Wireless Networks

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Abstract—**Rapid growth in the evolution of wireless technologies and mobile user demands necessitates future wireless communication to be a conjunctive working of several heterogeneous networks with their complementary features. Roaming of mobile terminals with different access interfaces and technologies among dissimilar networks is inescapable depending upon the user demands. Anywhere, anytime, any type connectivity is the raising requirement for mobile users either for real time or non-real time services. Recent literature has brought out numerous vertical handoff protocols for the emergence of the best network. In this paper, we give an overview and categorization of various vertical handoff decision schemes with reference to their characteristics. We also have given a synthesis of various vertical handoff decision schemes against diverse parameters.**

Keywords- Heterogeneous Wireless Networks, Mobility Management, Vertical Handoff Decision, Network Selection

I. INTRODUCTION

The emergence of several wireless technologies supporting high data rate, multimedia services and coverage, smart mobile terminals with interoperable air interfaces and flexible software components, and IP based applications produced anytime, anywhere, any type service connectivity platforms for mobile users. Global wireless connectivity is aimed by the fourth generation (4G) wireless systems [1] [2]. Nonpareil global roaming and high data rate services elevated 4G from the former versions of wireless networks [3][4]. The design goal of 4G systems is to provide seamless movement of mobile terminals across heterogeneous networks by offering continuity of services while maintaining quality of service. Extremely conciliatory and adaptive convergence of several mobile terminals and network technologies backing built-in potentiality for seamless wireless access drives the architectural goals of 4G systems. It is also important to realize that the arrival and deployment of more wireless technologies offering versatile services can add to the complexity of hand off process (refer to TABLE I). Fig.1 and Fig. 2 depict the heterogeneity of various networks with respect to the coverage and data rate respectively.

Tracking the location of the mobile subscribers, allowing continuity of calls and other services is the objective of mobility management. Mobility management is the combination of location management and handoff management. Change of point of contact (Base station) while maintaining continuity of services of a mobile terminal during its roaming, is ensured by handoff management [1]. The events that influence handoff management are mobility scenarios, network conditions, user preferences, network selection strategies (handoff decision techniques) for the selection of best network and execution protocols. Every mobility scenario falls into either intra-system or inter-system roaming. Horizontal handoff takes place in intra-system roaming when a mobile terminal departs the regulated realm of one access router and enrols into the regulated realm of another access router within the same network. Whereas in inter-system roaming, vertical handoff takes place when a mobile terminal moves in between different network technologies for suitable connectivity reasons depending upon the type and quality of service demanded by the mobile user. Seamless network switching is the challenge of vertical handoff management. Evaluation of received signal strength (RSS) will be insufficient for making vertical handoff decision. Extra parameters such as network conditions, service type, network coverage, cost, power consumption, and user preferences should be taken in to consideration [5]. Finding the right time for handoff to happen is very crucial for handovers. Handoff mechanisms can be controlled in two ways, either network controlled or mobile terminal controlled mechanisms. Network controlled handover policies cannot determine the right time for handoff to take place because they cannot have the latest information of the current circumstances of the mobile terminal. Also network controlled mechanisms will not be suitable for execution of vertical handovers because a network cannot be aware of the characteristics of all other networks. Mobile controlled handoff decision schemes will be optimal for vertical handovers since a mobile terminal knows better of its current circumstances.

This paper demonstrates various vertical handover decision mechanisms. Vertical handover decision process determines the necessity of handoff, the right network and the right time for handoff to take place. Minimizing overall signal load, avoiding unneeded handoffs and meeting user demands are the aims of vertical handover decision schemes. The decision criteria function of vertical handoff includes the capabilities of mobile terminals, user demands, network conditions and application requirements. We have categorized the vertical handoff mechanisms into six kinds of strategies such as: RSS centred strategies, consumer centred strategies, and decision function based strategies, multiple attribute decision models, context aware models and fuzzy logic /neural network models.

The paper is organized into six sections including introduction. Section I gives introduction for heterogeneous wireless networks and handoff management. It also shows with empirical data the heterogeneity of various networks. Section II gives a detailed description of handoff management along with motivation for handoff decision issue. In section III, handoff management problem is discussed in depth. Section IV covers various handoff decision strategies along their pros and cons wherever necessary. In this section we also have given synthesized report of all strategies for various parameters. Section V contains conclusion of the study of various handoff strategies.

TABLE I
Depicts heterogeneity among various networks in terms of coverage, data rate, mobility and cost

Network	Coverage	Data Rate	Mobility	Cost
Satellite	World	High data rate fixed services up to 155 Mbit/s;	Very High	High
GSM/GPRS	35 Kilometers	30-40 Kbit/s	High	High
GSM/EDGE	20 Kilo meters	160-200 Kbit/s	High	High
UMTS	20 Kilo meters	42 Mbit/s with HSPA+	High	High
WiMax	30-50 Kilometers with line of sight; 3-10 Kilometers with non line of sight	72 Mbit/s	Medium/High	Medium
IEEE 802.11a	Approx. 10 kilo meters	54Mbit/s	Medium	Medium
IEEE 802.11b	200 -500 meters outdoor 50-100 meters indoor	1 Mbit/s to 11 Mbit/s	Low	Low
HiperLAN 2	30 – 150 meters	54 Mbit/s (over the air-rate)	Low	Low
IEEE 802.11g	30-130 meters	20 Mbit/s	Low	Low
HiperLAN 1	Approx. 100 meters	10-20 Mbit/s	Low	Low
Blue tooth	10 meters/33 feet	1-3 Mbit/s	Very Low	Low

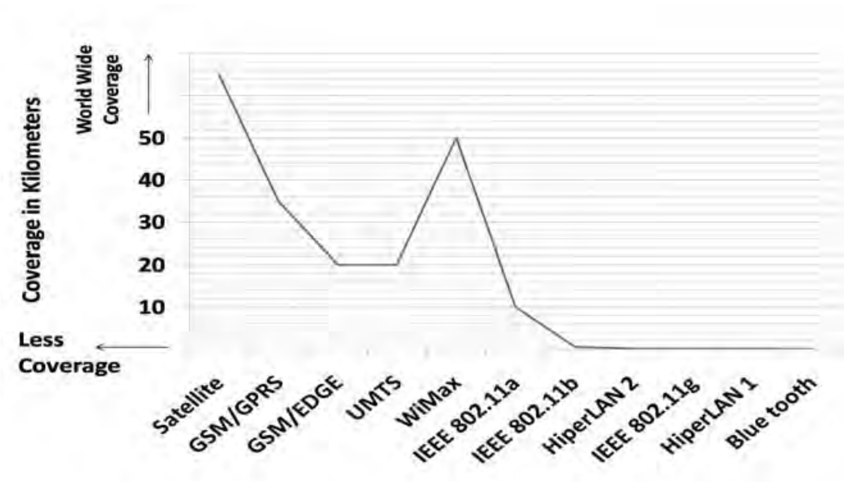


Fig. 1. Depicts heterogeneity of various networks with respect to coverage

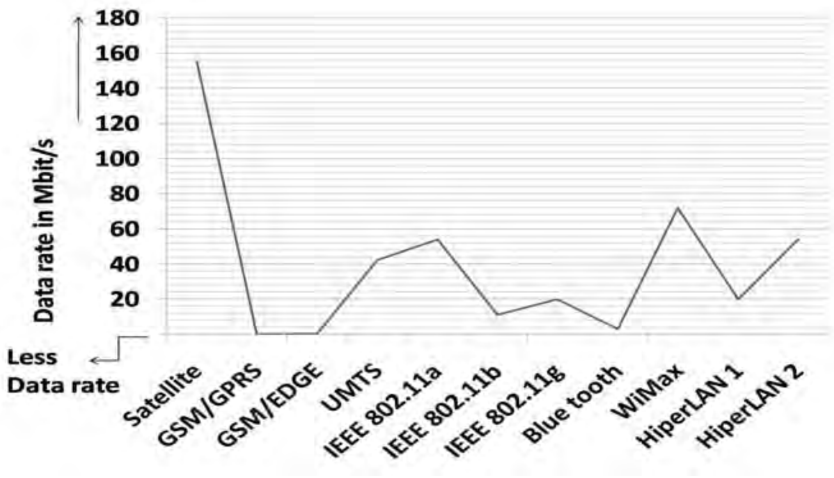


Fig. 2. Depicts heterogeneity of various networks with respect to data rate

II. HANDOFF MANAGEMENT

Increasing demand for the integration of various wireless technologies and internet, along with quick outgrowth in the number and the kind of services for mobile subscribers has caused mobility management, a challenge for 4G systems. Mobility management is the coalition of location management and handoff management. Location management is pertained with the set of network protocols which are responsible for allowing the mobile users reachable anywhere in the network coverage area. Upholding quality of service while reducing signalling overhead and latency are the functional goals of location management. Handoff management is the process by which a mobile terminal keeps its connectivity alive while travelling from the regulated realm of one base station into the regulated realm of another base station.

In this section, we discourse vertical handoff management process and also furnish motivation for examining vertical handoff decision problem on heterogeneous platforms.

A. *Handoff Management Process*

The entire vertical handoff management process can be fractioned into three steps such as handoff initiation, handoff decision and handoff execution [6-8]. The aim of handoff initiation phase is to discern the necessity of handoff and initiating it if required. In this phase,

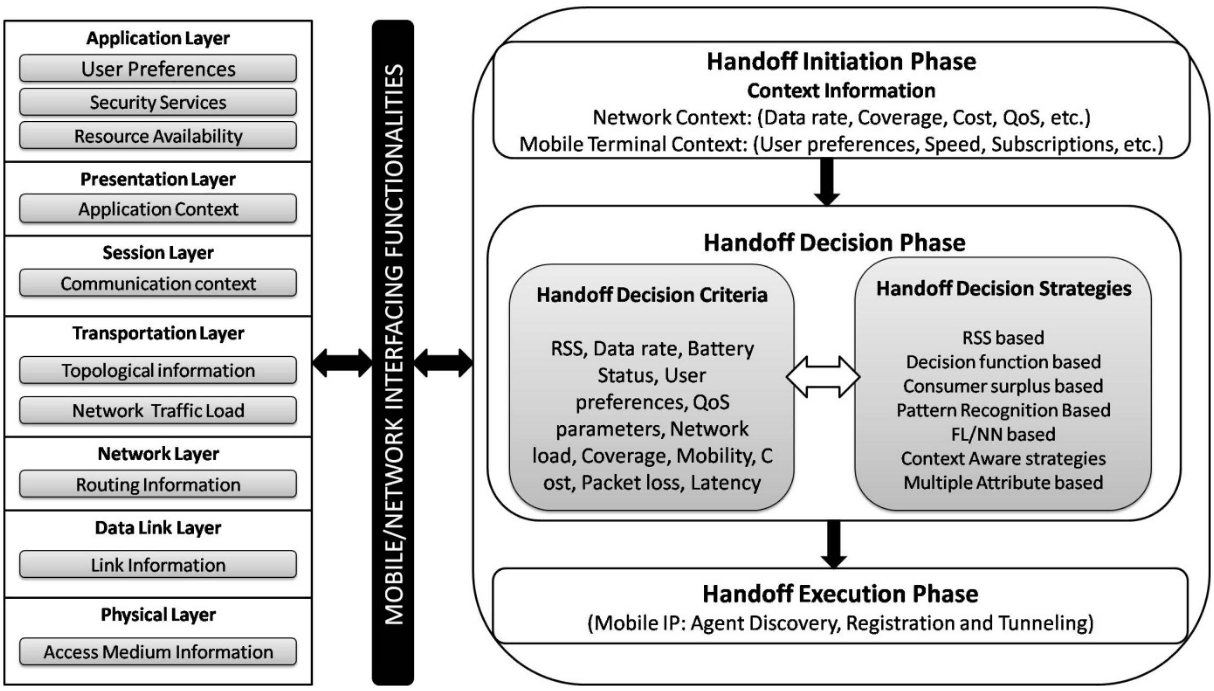


Fig. 3. Handoff management Process in collaboration with network layers

selective information of parameters such as RSS, bandwidth, link speed, network load, throughput, jitter, cost, power consumption, user preferences and network subscriptions will be accumulated. Various events triggered at various layers can be used as channels for collecting the information. The best network for handoff and the right time for handoff – these two queries primarily drive the functionality of handoff decision phase. In handoff execution phase, handoff process will be executed. In this phase, mobile terminal context and the profile of the user will be transferred to the new network. Security measures such as authentication and authorization will also be executed in this phase. Fig. 3 depicts handoff management process.

A. *Types of Handoffs*

Handoffs are classified as two types with respect to the behaviour of a mobile terminal for allowing itself for a new connection. They are hard handoffs and smooth handoffs. A handoff in which a mobile terminal releases its existing connection with a base station before allowing itself connect to a new base station is considered as hard handoff. A mobile terminal connecting itself with a new base station before releasing its already existing connection is treated as soft handoff. Handoffs are classified as four types with respect to 'who controls the handoff decision'. Fig. 4 depicts classification of various types of handoffs. If the control agent for handoff decision resides on the network side then it is called as network controlled

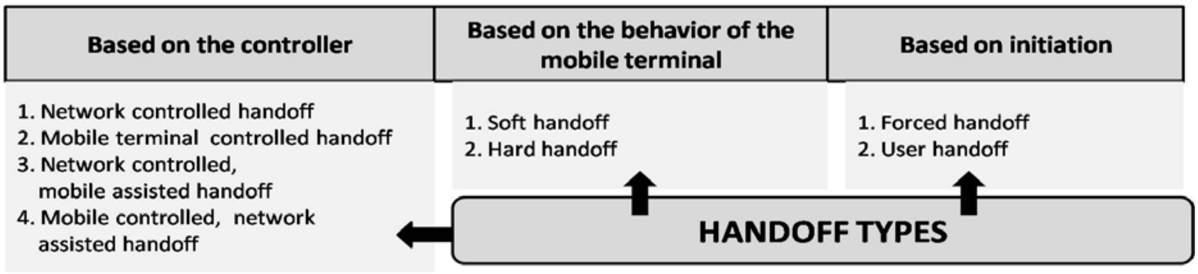


Fig. 4. Classification of handoffs

handoff (NCHO), if it resides on the mobile terminal then it is called as mobile controlled handoff (MCHO). If the mobile terminal assists the control agent, who is on the network side, in giving the primary information then it is called as mobile assisted handoff (MAHO). In case, if the network assists the control agent who is on the mobile terminal side then it is called as network assisted handoff (NAHO).In addition to the classifications given above, based on the kind of initiation, handoffs can be classified as forced handoffs and user handoffs. Forced handoffs are mandatory handoffs which are initiated due to potentially inconvenient network conditions. User handoffs are initiated due to user preferences.

B. *Design goals of handoff management schemes*

The design goals of handoff management schemes can be given as:

1) The algorithm designed for handoff process should be very fast so as to avoid the mobile terminal from going through any kind of service degradation or interruption.

2) Total number of handoffs required over a satisfactory service should be fully scaled down improving communication quality and reducing the total time spent on handoffs.

3) Loss on the total amount of information during the handoff process should be eliminated to the least possible extent.

4) New call blocking probability should be reduced.

5) Power conservation over the entire handoff process should be raised.

6) Network resources should be used expeditiously.

7) Handoff algorithm should be context aware at the same time giving priority to the user's preferences.

8) The handoff should be reliable which means that the services offered should be satisfactory once the handoff took place.

9) Handoff algorithm should be flexible, scalable and secured.

C. *Mobile Internet Protocol (Mobile IP)*

Mobile IP is one of the handoff management protocols [9]. IP version 4 presumes that mobile terminals are in constant physical positions. A correspondent node (CN) cannot transmit packets to a mobile terminal which is not in the home network. Hence mobile IP was introduced as a way for transparently dealing with the concerns of mobile users. A mobile IP brings in entities like, mobile node (MN), correspondent node (CN), home agent (HA), foreign agent (FA) and care-of-address (CoA). It also endorses services such as agent discovery, registration, encapsulation and de-capsulation. In agent discovery phase, a mobile agent recognizes the presence of a new network by hearing to the advertisements broadcasted by a FA. In registration phase (refer to Fig. 5), a MN registers its CoA with the HA through the FA. Encapsulation is the method used by the HA to deliver information to the MN by putting an extra IP header on top of the packet and tunnelling (refer to Fig. 6) that packet to the MN, which is on a foreign network. Some salient features of mobile IP are

1) Mobile terminals can continue to be connected with the internet irrespective of their locations.

2) IP addresses of mobile terminals need not be changed for tracking purposes.

3) Non mobile terminal's software components require no changes.

4) Some extra infrastructure is necessary.

5) There are no geographical restrictions.

6) Security measures are enforced.

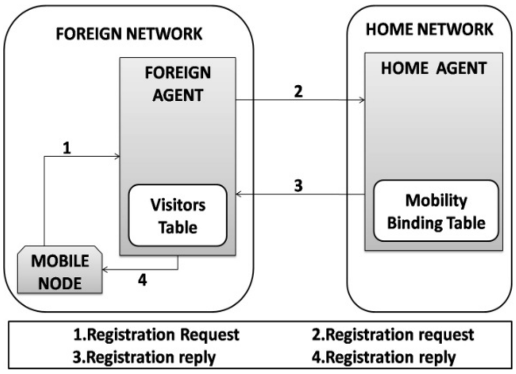


Fig. 5. Registration process in Mobile IP

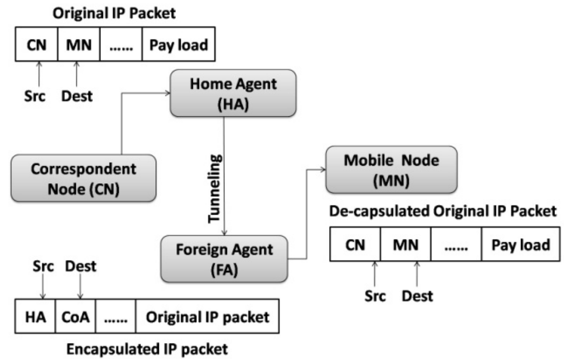


Fig. 6. Tunnelling in Mobile IP

D. Motivation for Vertical Handover decision Issue

In case of heterogeneous networks, the functionality of the handoff initiation phase and the handoff decision phase are different, where as in homogeneous networks, handoff initiation phase and handoff decision phase are combined into a single phase called handoff initiation phase. Since, in homogeneous networks, handoff is in between different cells of the same wireless technology, there is nothing called "choosing the best network". In homogeneous networks, it is enough for the received signal strength value to decline below certain threshold value to quick off horizontal handoff. Where as in case of heterogeneous networks, handoff decision phase cannot depend only on received signal strength, but different network characteristics such as user network subscriptions, bandwidth, coverage of mobility, latency, power consumption and cost etc. should be taken into considerateness. Counting on the user demands, mobile terminal features and network conditions, best network will be selected for vertical handoff. We compare and analyze various handover mechanisms against questions such as, what are the network characteristics considered for handoff decision process? What are the policies employed in making the handoff decision? Who is controlling the decision process either mobile terminal or the network? Is there any room for performance gain in terms of quality of service and cost benefits for the user?

Consequently, the challenging issue is tuning up the performance of handoff initiation and handoff decision mechanisms. Handoff initiation deals with discovering the network conditions to discern the necessity of handoff and therefore initiating it. Handoff decision deals with choosing the best network for handoff depending upon the service demands of the end user, mobile terminal features, and finding the right time for execution of the handoff decision. Identifying the decision criteria and decision policies to optimize the performance of handoff mechanisms is the ultimate objective of this paper.

III. VERTICAL HANDOFF DECISION PROBLEM

Every vertical handoff decision strategy consists of two stages: Identifying the handoff decision criteria and choosing the decision policy to be implemented. Handoff decision criteria consist of monitoring the network conditions which can give an indicant of the necessity of handoff. Fig. 6 depicts different categorizations of decision criteria describing network and mobile terminal conditions. Handoff decision criteria are used to choose the best network. Handoff decision policy uses decision criteria to choose best network by taking into consideration the performance of the handoff decision. Handoff decision policy mainly concerns about the consequences of the handoff decision such as frequency of handoff, latency induced by handoff, packet loss during handoff, overall quality of service after the handoff. A handoff decision policy can be designed based on various policies/algorithms such as consumer surplus algorithms, pattern recognition algorithms, fuzzy logic and neural

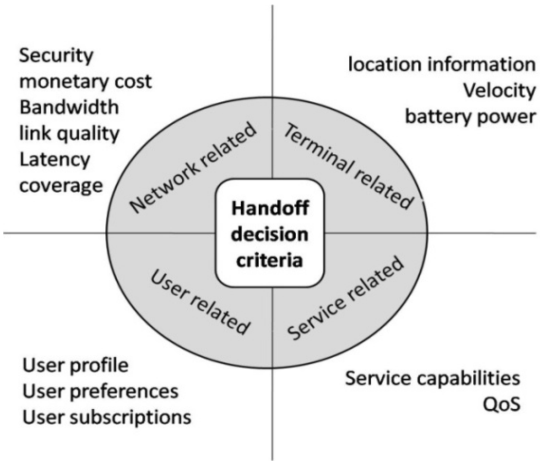


Fig. 6. Handoff criteria categorization

networks based algorithms, context aware algorithms, signal threshold based algorithms, position aware algorithms, multi attribute algorithms and function based algorithms. Though availability of multiple decision criteria and consideration of user preferences can increase the complexity of the design of handoff policy, optimum performance is the objective of every handoff policy.

IV. Vertical Handoff Strategies

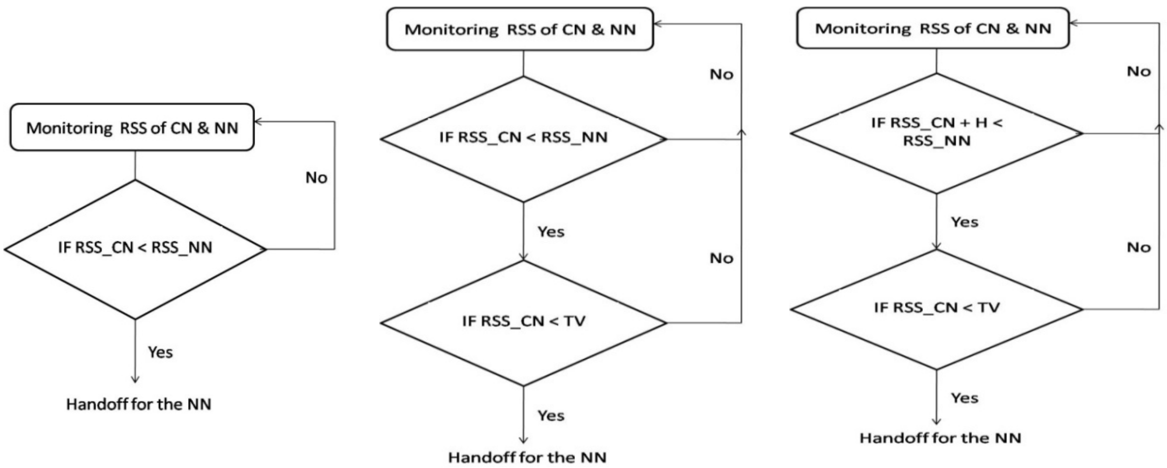
In this section, various design strategies for handoff decision policy are discussed in brief exploring pros and cons of every strategy. Design of an optimum performance vertical handoff policy is the aim of the study.

A. *RSS Centered Strategies (RCS)*

Traditional strategies are mostly centered on the value of RSS. Three simple traditional strategies of RSS are explained with the help of flow charts in Fig. 7. The flow charts can also be expressed as simple rules for handoff decision. These rules are just based on comparison of various combinations of RSS of current network, new network, threshold value and hysteresis value [10] [11]. RSS centered strategies do not consider the following components:

1) User preferences
2) Mobile terminal context information
3) Network context information
4) Application demands

Designing a handoff decision policy which can offer QoS, user satisfaction and cost effectiveness cannot depend solely on RSS value. Design of such policy should definitely consider other parameters such as mobile and network context information, user preferences and application demands. The forthcoming sections discuss in detail various strategies for the design of handoff policy which are not simply based on RSS value.



CN – Current Network, NN – New Network, TV – Threshold Value, H - Hysterisis
Fig. 7. Three simple RSS centered handoff strategies

B. *Consumer Centered Strategies (CCS)*

Consumer centred strategies design vertical handoff decision algorithms that consider consumer preferences aiming consumer's satisfaction. Cost and QoS are the two primary factors to be considered for consumer's preferences. Many consumer preferences based vertical handoff policies have already been proposed.

In [21] A. Calvagna et al. have given a consumer centred analysis of vertical handovers. They have proposed two threshold value based policies for integrated GPRS-WIFI platforms. In the first policy, the mobile terminal abandons its connection with GPRS only when there is a connection blackout. This policy satisfies the user whose priority is only QoS, not cost (refer to Fig. 8). In the second policy, WIFI access points with connection blackouts are searched for mobile user's connections. This policy is for users whose priority is cost, not QoS (Fig. 9). Failing to find a balance between QoS and cost can lead to extreme performance. In view of gaining optimum performance, cost function is defined to as:

$$C = T_{GPRS} * C_{GPRS} + T_{WIFI} * C_{WIFI} \quad (1)$$

$T_{GPRS} =$ Time spent by the mobile user over GPRS connection

$C_{GPRS} =$ Cost per unit time over a GPRS network

$T_{WIFI} =$ Time spent by the mobile user over WIFI connection

$C_{WIFI} =$ Cost per unit time over a WIFI network

$C =$ Total cost generated for a given communication session

The proposed method contains three modules: Network selection process module, network monitoring module and user-centric module. Network monitoring module and user-centric module are responsible for reporting network and user preferences related information respectively to the network selection process module. QoS priority policy and cost priority policy both are part of network selection process module. The proposed

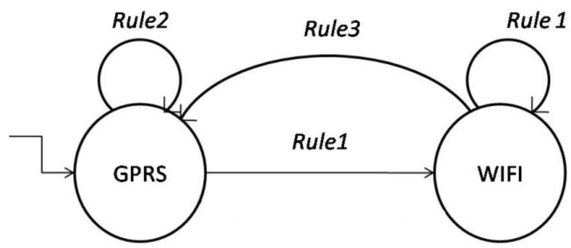


Fig. 8. QoS priority policy

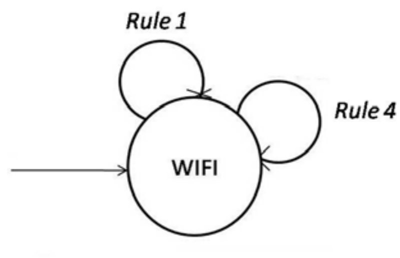


Fig. 9. Cost priority policy

GCB = GPRS Connection Blackout
WCB = WIFI Connection Blackout
GC = GPRS Connection
TV = Threshold Value

Rule 1: IF GCB= TRUE
Rule 2: IF GCB = FALSE
Rule 3: IF GC > TV
Rule 4: IF WCB = TRUE OR FALSE

model was implemented with the help of a distributed mobility protocol which supports roaming of mobile terminals on GPRS – WIFI integrated platforms.

In [22], a vertical handoff decision model was proposed for non real time services. Network selection is based on consumer surplus value. Consumer surplus value is the difference between the original price for the amount of data transferred and the actual price charged. Decision metrics are designed based on user's choices for various combinations of delay and associated monetary value. Few of the choices are designed as: *less delay irrespective monetary value, less delay and assured monetary value benefiting the user, less monetary value based on the quantified value of delay, absolutely less monetary value irrespective of delay.* Appropriate utility function will be selected once user's choice is read. A wired network with two WLAN access points with multi homed terminal is used by the simulated model. A consumer surplus based network selection strategy is deployed. It is observed by simulated results that the utility function selected is dependent on the amount of data to be transferred. Few drawbacks of consumer centred strategies are given below:

1) Low context awareness
2) Low adaptability
3) Low scalability

The above mentioned consumer centred functions focus primarily on user satisfaction. But consumer satisfaction cannot be thought only in terms of cost. To achieve better QoS, more advanced techniques and elegant selection criteria should be employed for efficient selection of a network in maximizing user satisfaction.

C. Decision Function Based Strategies (DFBS)

Decision function is quantification of the benefit attained due to handoff. Every parameter in the decision criteria is assigned a weighted function. The sum of all the weighted functions of the decision criteria is the result of decision function for a network. A decision criteria set for network n with m parameters will be having m weighted functions. Decision function for the network n can be given as

$$f_n = w_{p1}.c_{p1} + w_{p2}.c_{p2} + \cdots + w_{pm}.c_{pm} \tag{2}$$

$w_{px} =$ *weight assigned to parameter x in decision criteria of network n.*

$c_{py} =$ *cost assigned to parameter y in decision criteria for network n.*

General form of a decision function for service s of a network n can be given as

$$f_n = \sum_{p=1}^{m} w_{s,p} \cdot c_p^n \tag{3}$$

$w_{s,p} =$ *Weight assigned to parameter p for service s*

$c_p^n =$ *Cost incurred for parameter p for service s in network n*

The cost function of a network (f_n) for an application with z services can be given as

$$f_n = \sum_{s=1}^{z} \sum_{p=1}^{m} w_{s,p} \cdot c_p^n \tag{4}$$

Number of services in an application varies from 1 to z and number of parameters for each service varies from 1 to m.

In [26], H. Wang et al. proposed a cost-function for a mobile controlled network assisted handoff mechanism to select the best network. The cost of using a network n is defined as:

$$f_n = w_b.N\left(\frac{1}{B_n}\right) + w_p.N(P_n) + w_c.N(C_n) \tag{5}$$

$B_n =$ *Bandwidth offered by the network n*

$P_n =$ *Power Consumption of network device for using the network n*

$C_n =$ *Monetary cost for using the network n*

$N(i)$ *is normalization function for the parameter i*

$w_b =$ *Weight assigned to bandwidth*

$w_p =$ *Weight assigned to power consumption*

$w_c =$ *Weight assigned to cost*

Network with the lowliest cost function value will be the right one for handoff to take place. The proposed cost function works efficiently for dynamically altering conditions of the network. The policy also inducts a waiting time to ascertain the worthiness of the calculated handoff. It also clearly differentiates between decision module and the handoff module offering higher flexibleness. The performance of the handover mechanism can also be improvised by controlling the network load. A special case of performance issue of this regard is preventing many mobile terminals to take handoff at the same time over to the same network. This is achieved by implementing a performance agent which collects bandwidth information from the base stations and broadcasts the same to the mobile terminals in the coverage area.

In [27], W. Chen et al. proposed a utility function based model to analyse and quantify the QoS of eligible networks. It reduces number of handoffs and increases the speed of handoff process for which two adaptive handoff decision methods are proposed for tuning the constancy period defined in [26]. The first method calculates utility ratios of the current network and the target network and the second one uses utility ratios calculated by the first method to find out the best network for handoff. An adaptive interface is also proposed for the two adaptive methods. The mobile terminal takes the responsibility of activating the adaptive interface based on its distance from the base station with the assistance of location service server. Thus system discovery time is reduced increasing the speed of handoff process. It is implemented on WLAN and WWAN types on networks.

Major drawback of decision function strategies is that they are not flexible thus scalability is very low. These strategies fail upright in handling imprecise data. They also do not consider device properties and application demands and are not aware of mobile and network contexts.

D. Multiple Attribute Decision Making Strategies (MADMS)

Handoff decision problem can be easily mapped to multiple attribute decision making problems (MADM). Identifying the objectives and measuring the effectiveness of the selected objectives are the two most important steps in MADM methods. Application of basic decision trees may not be a suitable solution for handoff decision algorithms because of their limited ability to handle the complexity associated with the competitive decision criteria. Multi-attribute decision analysis makes use of multi attribute utility theory to formalize a common unit's assessment and specify the decision maker's preferences for each attribute across respective units scale [23]. Identifying the attributes influencing the decision objectives, normalizing the attributes across the alternatives, weighting the user's preferences are the three important steps of multi attribute utility theory. Fig.

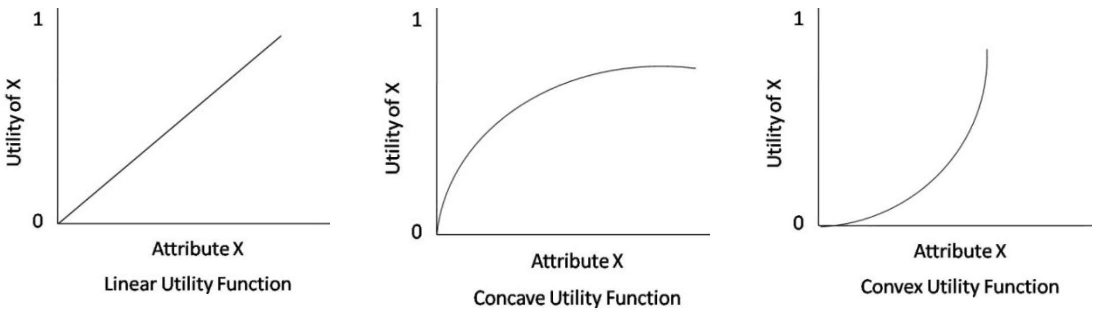


Fig. 12: Various utility functions for decision criteria attributes

12 depicts various utility functions for decision attributes. After initializing the preferences for attributes, the decision making functions ascribe weights to the preferences in a multi-attribute utility function of the form:

$$U(x_{1,}x_{2,} \ldots\ldots x_n) = k_1U(x_1) + k_2U(x_2) + k_3U(x_3) \ldots\ldots + k_nU(x_n) \quad (6)$$

k's are the weights ascribed to each of the attributes such that $k_1 + k_2 + k_3 + \cdots + k_n = 1$

Below are given few of most famous MADM methods.

1. Simple Additive Weighting (SAW): The sum of the weights of all attributes values determines the score of a candidate network.
2. Technique for order preference by similarity to ideal solution (TOPSIS): This method classifies the attributes into three types: Qualitative benefit criteria, quantitative benefit criteria and cost criteria. It defines two artificial alternatives: *ideal alternative* and *negative ideal alternative*. The network with score closest to the ideal solution and farthest from the negative ideal solution is determined as the right candidate for vertical handoff.
3. Analytic Hierarchy Process (AHP): The available data is broke up into a hierarchy of choices and criteria. Data is then synthesized to find comparative ranking of the available choices.
4. Gray relational Analysis (GRA): This method defines two extreme points: systems with no information and systems with perfect information. Every system in between these systems is defined as a grey system. Systems with no information can not contain any solutions; but systems with perfect information contain unique solution. This method ranks all the user subscribed networks and the network with the highest rank will be chosen for the handoff process.

In [24], E. Stevens-Navarro et al. equated three of the four models for the attributes such as bit-error-rate, jitter, delay and bandwidth. It is observed that GRA gives better performance than SAW and TOPSIS in terms of bandwidth and latency for interactive and back ground classes of traffic. SAW and TOPSIS showed almost same kind of performance for the given traffic classes. It can be concluded that the weights ascribed to the decision criteria attributes will greatly influence the performance of the decision process.

In [25], S. Quiqyang et al. proposed a model which is a combination of AHP and GRA. AHP ascribes weights to the QoS parameters whereas GRA ranks all the eligible networks. Simulation results have shown that the model works efficiently on UMTS – WLAN integrated platforms.

AHP is widely used and well established method for multi-criteria decision making. It permits both qualitative and quantitative criteria for valuation. Once, AHP [18] builds a hierarchy of decision criteria, the following two actions are carried out

1. Find out the comparative weights of the decision criteria.
2. Find out the comparative rankings of the alternatives.

Ascribing weights to the attributes starts with reasonable assumptions. Attributes with highest priority, as per the user preferences and application requirements, will be given highest weight upon the pre-defined scale of weights. Combing multiple attribute decision making methods with more advanced strategies such as fuzzy logic, neural networks, pattern recognition etc. will yield better handoff decisions in situations where data is imprecise.

The only limitation of MADM methods is ‘the speed of handoff is not really fast’ due to computational complexity. The time to rank the available networks is also comparatively high due to the same reason.

E. Context Aware Strategies (CAS)

The aim of context aware vertical handoff decision model is to choose the best network among the available networks. The decision for the right network will be greatly influenced by the type of application demanded by the mobile user. It is very important to find a balance between the requirements of the application and the primary objectives of the user, both subjected to the context of the network and mobile terminal. The analytic hierarchy process (AHP) [18] is an established method for selecting the best choice amongst many choices.

In [19], T.Ahmed et al. proposed context aware decision model by considering mobile initiated and mobile controlled vertical handoff decision approach. Once after defining the primary objectives, the contexts for the decision algorithm are modelled as static and dynamic. Fig. 13 depicts the context models for the decision algorithm. The preferences given by the mobile user should meet both the requirements of the application and also the mobile terminal capabilities. The proposed architecture contains five stages, two of which are pre-configuration stages and the remaining three are part of real time calculations stage.

Stage 1: User preferences: The user should give three categories of information: primary objectives, properties of the mobile terminal and the application properties.

Stage 2: Assigning boundary values to QoS parameters: In this stage, appropriate upper and lower bounds for QoS parameters are assigned based on the user preferences.

Stage 3: Giving scores to user subscribed networks: In this stage appropriate scores are assigned to all the reachable and user subscribed networks based on limits assigned to the QoS parameters.

Stage 4: Computing network ranking based on AHP method: Based on priorities of objectives and scores assigned to user subscribed networks rank of each network is calculated.

Stage 5: Session Management: This stage deals with deployed session transfer scheduling algorithms to switch mobile user applications to the new network.

The proposed algorithm can be extended to include user’s location, speed and network coverage into consideration. In [21] decision hierarchy for context aware decision algorithms is also proposed.

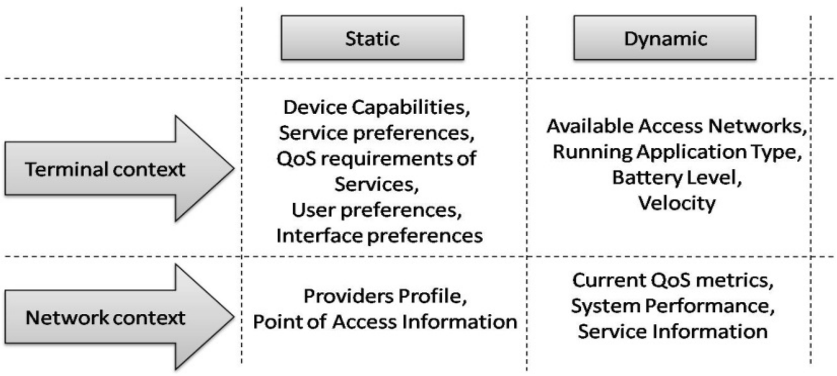


Fig: 13. Context models for the decision Algorithms

In [20], S. Balasubramaniam et al. proposed a context aware vertical handoff model for pervasive environments with the assumption that application QoS is specified as user perceived QoS. Contexts are modeled as static profile and dynamic profile. The proposed architecture contains two modules: context repository module and adaptability manager module. Information related to various network contexts such as QoS parameters of the network, network devices etc. will be maintained by the context repository module. Handoff mechanism is designed as a rule based system. Vertical handoff initiation and decision with respect to the changes in the context will be handled by adaptability manager. Handoff mechanism is designed as a rule based system. A locality based network selection (LBNS) mechanism is employed to determine changes in the context and to perform handoff to a new network. The solution is classified as a mobile assisted solution. The rules defining the handoff mechanism are given below:

Rule 1: Call LBNS to determine current device, current network for application initialization.

Rule 2: If the user reaches the transition zone of the current network and initiates vertical handoff process, then call LBNS to decide new network.

Rule 3: If the user gets into a new network then call LBNS to find out the new network based on application QoS parameters.

Rule 4: In case of changes in QoS parameters, perform handoff with the best network if the current network score falls below the scores of the other available networks.

Drawbacks:

1) Deployment of single context repository can easily cause single point of failure.
2) Since different parts of the entire system (network + mobile terminal) communicate with the context repository for every change, this increased communication can increase the total network traffic resulting unnecessary overhead over the radio link.

Context aware strategies can become very efficient when they are built with MADM and Fuzzy logic models. The only challenge in context aware strategies is "*how efficiently a context can be understood*" to make the handoff decision.

F. Fuzzy Logic and Neural Networks Based Strategies (FL/NN)

Fuzzy logic (FL) and Neural network (NN) approaches are generally used to model behavioral systems. Fuzzy logic approaches come into play in contexts where decision criteria contain inaccurate information. Also handoff decision algorithms which are driven by multiple attributes can be tuned for high performance by FL strategies. Fig. 14 depicts a fuzzy inference system. We have to define the inputs and outputs to the system and also assign membership functions to the input and output variables. Rule base generated from expert systems is constructed for the input and output variables based on IF-THEN, AND, OR rules.

In [12], K. Pahlavan et al. proposed an advanced three layer back propagation NN architecture applied for pattern recognition aiming the bandwidth requirements of the end users. It discovers decline in the RSS to induct the handoff. In the experiments conducted over Mobile IP supported WLAN – GPRS platforms, the RSS samples received from various access points are given as input to the handoff initiation system. The outputs are either zero or one. Zero indicates that the mobile terminal can continue its connection with the current network. Otherwise, it should initiate handoff. It was shown with simulations that the proposed architecture yields better performance than the traditional RSS based handoff mechanisms in terms of handover latency and loss of information caused by number of handovers. But the proposed system suffers cost ineffectiveness due to huge configuration demands and also it requires beforehand information about the radio network.

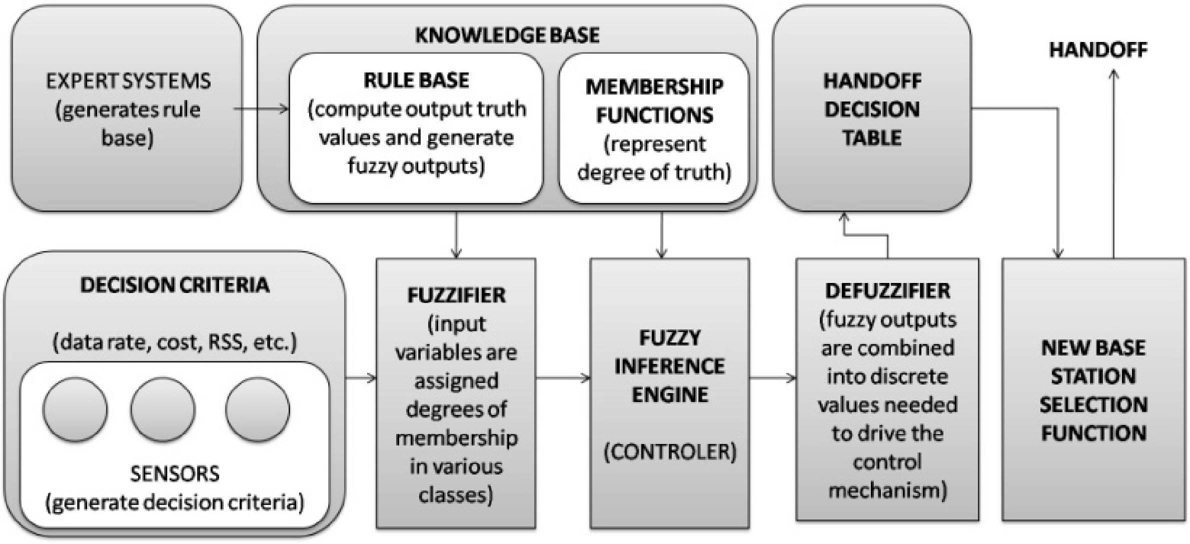


Fig. 14. Fuzzy Inference System supported by expert system and sensors

In [17], K.Vasu et al. proposed a QoS aware fuzzy model for applications which are delay sensitive considering bit error rate, E2E delay, Jitter and bandwidth as QoS parameters. They also proposed an evaluation model by using non birth-death Markov chain for comparing several vertical handoff decision algorithms. In [14], P. Chan et al. proposed a fuzzy model integrating UMTS, GPS and satellite mobile networks. Decision criteria are evaluated against user preferences to choose the best network for handoff.

In [16], Guo et al. proposed an adaptive multi-criteria vertical handoff decision algorithm for radio heterogeneous network. It consists of a modified Elmann Neural Network model to predict the number of users on the new network after the handoff, and a fuzzy inference system for the evaluation of the decision criteria enabling the handoff decision. Simulations performed for WLAN – UMTS scenarios showed that the proposed systems perform better than the traditional RSS based methods. In [13], J. Makela et al. proposed a system incorporating geographical capabilities into WLAN facilitating exchange of location information among IP devices. Any MT entering the realm influenced by the WLAN can communicate with access point (AP) and take handoff to the WLAN for better bandwidth requirements. Generally, estimating the right time for handoff decision is done by NN approaches, where as FL strategies can be, used both for estimation of right time and right network for handoff.

G. Synthesis

Study of various vertical handoff strategies showed that design of an efficient vertical handoff algorithm is always subjected to user satisfaction. Efficiency should be realized as a relative term with respect to user preferences. User preferences may change from service to service or application to application. The objective of every vertical handoff algorithm should be meeting the preferences of user; thus efficiency of an algorithm is defined.

One of the major challenges identified for vertical handoff algorithms is on ‘how to deal with imprecise data’. Only fuzzy logic seems to be the ideal choice among the available strategies to deal with imprecise data. Though multi attribute decision models are proven mathematical models, providing precise data as input for vertical handoff is very important. MADM models built with fuzzy logic modules can lead to effective vertical handoff decision algorithms.

Another parameter that affects vertical handoff algorithms majorly apart from user preferences is contextual information. It is very important to understand the contextual information of the user subscribed networks, mobile terminal and application in demand properties while making the vertical handoff decision. It is also observed that no vertical handoff strategy considered ‘*user consciousness*’ as a parameter in their design. It is the aim of pervasive computing to bring down all computations to user’s subconscious level in order to protect user’s attention.

We believe that it is right time for researchers to work on pervasive approaches for vertical handoff. A general comparison of various handoff strategies for various parameters is given below in the TABLE II. This basic idea in developing this table is taken from [29].

TABLE III
Comparison of various strategies

Metrics	Vertical Handoff Decision Strategies					
	RCS	DFBS	CCS	MADMS	FL/NN	CAS
Multi decision criteria	No	Yes	Yes	Yes	Yes	Yes
Context Awareness	No	Low	Low	Medium	High	High
Device properties	No	Low	Low	Medium	High	High
Frequency of Handoff	High	Medium	Medium	Low	Low	Low
Loss of information	High	Medium	Medium	Low	Low	Low
*Overall Time on handoff	High	Medium	Medium	Low	Low	Low
*Overall Power Consumption	High	Medium	Medium	Low	Low	Low
*Overall Delay	High	Medium	Medium	Medium	Low	Low
Bandwidth utilization	Low	Medium	Medium	Medium	High	High
Computational Memory Requirement	Low	Medium	Low	High	High	High
User Preferences	No	Low	High	High	High	High
speed of handoff	High	Medium	Medium	Medium	Medium	Medium
Adaptability	Low	Medium	Low	Medium	High	High
Implementation Complexity	Low	Medium	Medium	Medium	High	High
Configuration Cost	Low	Low	Low	Low	High	High
Services supported	Non real time	Real Time and Non-real time	Non real Time	Real Time and Non-real time	Real Time and Non-real time	Real Time And Non-real time
User Consciousness	No	Low	High	Medium	High	High
System Scalability	Low	Low	Low	Medium	High	High
efficiency of the decision	Low	Medium	Medium	Medium	High	High
*Overall QoS	Low	Medium	Medium	Medium	High	High

* Overall represents one complete session of communication between mobile user and base station.

V. CONCLUSION

Heterogeneous wireless network is integration of various networks with complementary features with the aim to offer various high quality services. Vertical handoff is an essential feature required for mobile terminals to roam seamlessly across these multi-service networks. Vertical handoff decision is fundamental issue to be addressed for offering seamless services. It is this decision phase that should consider various parameters such as mobile and network context information, user preferences and QoS parameters etc. In this paper, a study of various handoff strategies with proper classification is presented. It is clearly concluded that advanced analytical strategies are mandatory for an efficient handoff decision process which can increase user satisfaction with cost effectiveness at the same time giving best utilization of network resources. Two key issues every efficient handoff process should estimate are the best network for handoff to take place and the right time for handoff. Other important issues to be considered are: who controls and who assists the handoff process. Information gathering phase and performance evaluation framework for the handoff process are also among the other key issues to be dealt. In the synthesis section, we also have given a comparison of various strategies for various parameters such as frequency of handoff, scalability, overall performance etc. We also have proposed a new model for the vertical handoff process with pervasive approach for user preferences. The proposed model considers MADM, FL and context aware strategies to increase user satisfaction achieving optimum performance. We will be considering the proposed model for future work.

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