A Dynamic Decision Model for Vertical Handoffs across Heterogeneous Wireless Networks

Pramod Goyal, and S. K. Saxena

Abstract—The convergence of heterogeneous wireless access technologies characterizes the 4G wireless networks. In such converged systems, the seamless and efficient handoff between different access technologies (vertical handoff) is essential and remains a challenging problem. The heterogeneous co-existence of access technologies with largely different characteristics creates a decision problem of determining the "best" available network at "best" time to reduce the unnecessary handoffs. This paper proposes a dynamic decision model to decide the "best" network   at "best" time moment to handoffs.   The proposed dynamic decision model make the right vertical handoff decisions by determining the "best" network at "best" time among available networks based on, dynamic factors such as "Received Signal Strength(RSS)" of network and "velocity" of mobile station   simultaneously with static factors like Usage Expense, Link capacity(offered bandwidth) and power consumption. This model not only meets the individual user needs but also improve the whole system performance by reducing the unnecessary handoffs.

Keywords—Dynamic decision model, Seamless handoff, Vertical handoff, Wireless networks.

I. INTRODUCTION

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

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

Authors are with Department of Computer Engineering, Delhi College of Engineering,   University   of   Delhi,   Delhi,   India   (e-mail: pkgoyal03@yahoo.com, saxena_58@yahoo.com).

This paper propose a dynamic decision model to make the right vertical handoff decisions by determining the "best" network at "best" time among available networks based on, dynamic factors such as "*Received Signal Strength (RSS)*" of network and "*velocity*" of mobile station   as well as static factors. Thus this model not only meets the individual needs but also improve the whole system performance by reducing the unnecessary handoffs.

II. STATE OF THE ART

As per the present knowledge, there exist very few works dealing with Vertical Handoff (VHO) beyond simple extensions to the common techniques for Horizontal Handoff (HHO). Three main approaches for VHO algorithms are recorded in the literature. The *first approach* is based on the traditional strategies of using the RSS that may be combined with other parameters such as network loading. The *second approach* uses artificial intelligence techniques combining several parameters such as network conditions and Mobile Terminal's (MT) mobility in the handoff decision. However, these artificial intelligence based algorithms are complex and may be difficult to implement in practical systems. The *third approach* combines several metrics such as access cost, power consumption, and bandwidth in a cost function estimated for the available access networks, which is then used in the MT handoff decision.

Wang et al. introduce the policy enabled handoff in [5], which was followed by several papers on similar approaches. Policy enabled handoff systems separates the decision making (i.e. which is the "best" network and when to handoff) from the handoff mechanism. These systems allows users to express policies on what is the "best" wireless system at any moment and make tradeoffs among network characteristics and dynamics such as cost, performance and power consumption.

A generic vertical handoff decision function [6] proposed considering the different factors and metric qualities that give an indication of whether or not a handoff is needed. The decision function enables devices to assign weights to different network factors such as monetary cost, quality of service, power requirements, personal preferences etc.

A decision strategy [7] considers the performance of the whole system while taking VHO decisions by meeting individual needs. This decision strategy select the best

network based on the highest received signal strength (RSS) and lowest Variation of received signal strength (VRSS).thus it ensures the high system performance by reducing the unnecessary handoffs.

A time adaptive VHO decision scheme [8] make right VHO decisions timely through adjusting interface activating intervals based on the user's movement and the actual network performance.

All the schemes presented till now either used only static parameters or used only one dynamic parameter (RSS or velocity) with the static ones to improve the system performance but not both. So this paper proposed a dynamic decision model which used both RSS and velocity as dynamic factors to improve the system performance.

III. BACKGROUND

The Heterogeneous networks are expected to become a main focus in the development toward the next generation wireless networks. In the heterogeneous or converged network [13], both intra-technology handoff and inter-technology handoff take place as illustrated in Fig. 1. Intra-technology handoff is the traditional Horizontal Handoff (HHO) process in which the mobile terminal hands-off between two Access Points (AP) or two Base Stations (BS) using the same access technology. On the other hand, inter-technology handoff, or Vertical Handoff (VHO), occurs when the MT roams between different access technologies.
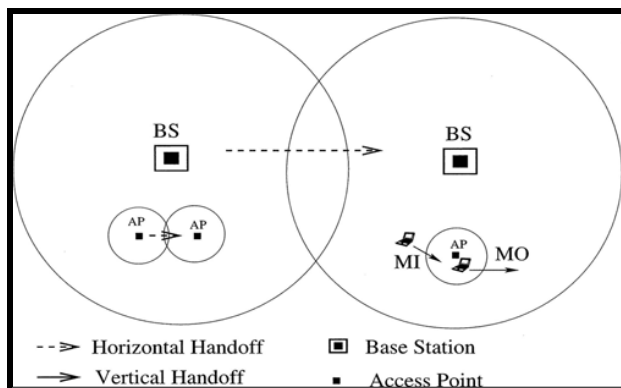

Fig. 1 Horizontal and Vertical Handoff

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

There are two main scenarios in VHO: *moving out of the preferred network (MO) and moving into the preferred network (MI).* In the converged model, it is highly desirable to associate the MT with the preferred network, as long as the preferred network satisfies the user preferences. This can

improve both, the resource utilization of access networks as well as the user perceived quality of service (QoS). Furthermore, this handoff should be *seamless* with minimum user intervention, while dynamically adapting to the wireless channel state, network layer characteristics, and application requirements.

In general, the vertical handoff process can be divided into three main steps [10], namely System Discovery, Handoff Decision, and Handoff Execution. During the system discovery phase, mobile terminals equipped with multiple interfaces have to determine which networks can be used and the services available in each network. The networks may also advertise the supported data rates for different services. During the handoff decision phase, the mobile device determines which network it should connect to. The decision may depend on various parameters including the available bandwidth, access cost, transmit power, current battery status of the mobile device, and the user's preferences. During the handoff execution phase, connections need to be re-routed from the existing network to the new network in a seamless manner. This phase also includes the authentication and authorization, and the transfer of user's context information.

A seamless handoff is defined as a handoff scheme that maintains the connectivity of all applications on the mobile device when the handoff occurs. Seamless handoffs aim to provide continuous end-to-end data service in the face of any link outages or handoff events. Various seamless handoff techniques [2] have been proposed. These proposals can be classified into two categories: network layer approaches and upper layer approaches.

Seamless handoff solutions, whether network layer or upper layer approaches, are often complex to implement and operate. For the network layer solutions, deployment means upgrading every existing router without mobile IP capabilities. For the upper layer solutions, a new session layer or transport protocol requires an update to all existing applications and servers not supporting it. In both the above cases, the high cost imposed by these solutions hinders their chances of deployment. Consequently, even though these handoff solutions have managed to minimize both latency and packet loss, they are often deemed impractical by the majority of service providers and are still rarely deployed in reality.

A Universal Seamless Handoff Architecture (USHA) was proposed in [3] to deal with both horizontal and vertical handoff scenarios with minimal changes in infrastructure which requires deployment of handoff servers only on the Internet. USHA is an upper layer solution; however, instead of introducing a new session layer or a new transport protocol, it achieves seamless handoff by following the middleware design philosophy, integrating the middleware with existing Internet services and applications. USHA is based on the fundamental assumption that handoff, either vertical or horizontal, only occurs on overlaid networks with multiple Internet access methods (i.e. soft handoff), which translates to zero waiting time in bringing up the target network interface when the handoff event occurs. If coverage from different access methods fails to overlap (i.e. hard handoff), it is

possible for USHA to lose connectivity to the upper layer applications.

In multi-network environments, Criteria of a vertical handoff is one of the chief challenges for seamless mobility as there does not exist a single factor than can provide a clear idea of when to handoff. Some of the most important decision factors are:

Usage Cost: The cost of using a network to the user is a major issue. The network providers may well provide a variety of billing plans and options that will probably influence the customer's choice of network and thus handoff decision.

Power Requirements: Wireless devices operate on limited battery power. When the level decreases, handing off (or remaining connected) to a network with low power consumption can provide elongated usage time.

Offered Bandwidth: Higher offered bandwidth ensures lower call dropping and call blocking probabilities, hence higher throughput.

Velocity: Because of the overlaid architecture of heterogeneous networks, handing off to an embedded network, having small cell area, when traveling at high speeds is discouraged since a handoff back to the original network would occur very shortly afterwards.

Signal Strength: The signal strength has a great role in the HHO decisions due to its comparability between the current attachment point RSS and that of the candidate attachment points. But In VHO, the RSSs are incomparable due to VHO's asymmetrical nature. However, they can be used to determine the availability as well as the condition of different networks. If more than one candidate networks are available, the MT should associate itself with the one having the strongest RSS as it does in HHO.

In the proposed Dynamic Decision Model, above mentioned criteria's are taken into consideration with special emphasis on velocity and RSS in order to improve the system performance by reducing the unnecessary handoffs.

IV. Dynamic Decision Model

This section presents the proposed Dynamic decision model which support flexible configuration in executing vertical handoffs. Fig. 2 depicts the proposed dynamic decision model. A Handoff Management Center (HMC), monitors the various inputs collected from the network interfaces and their base stations (BS), analyze this information and took handoff decisions. It also provides the connection between the network interface and the upper layer applications. HMC is composed of five components: Network Analysis (NA), Network Discovery (ND), Dynamic decision (DD), system monitor(SM) and Handoff manager & executor (HME).

NA is responsible for monitoring the status of each network interface (i.e. offered bandwidth, user charges, power consumption of network interface) and analyzing based on the calculated score function. SM monitors and reports system information (i.e. current remaining battery and user preferences) to NA module. ND module discovers all the available networks at fixed time intervals. It monitors the velocity of mobile station (MS) and the Received signal

strength (RSS) of the base station (BS), select the candidate networks and assigns them priorities. Finally, the DD module takes the decision, for selecting "Best" network to handoff, based on the inputs from NA and ND modules.
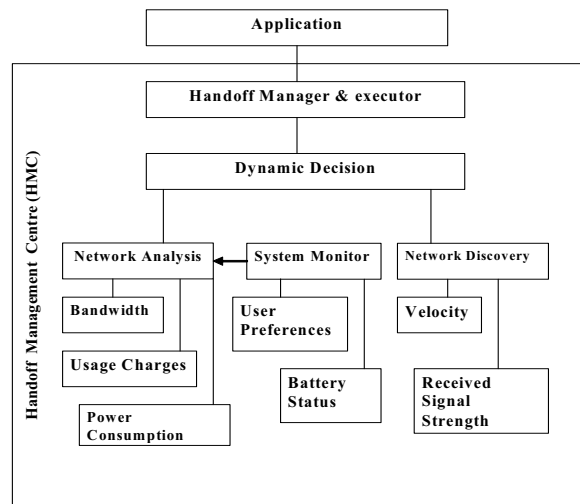

Fig. 2   Dynamic Decision Model

The algorithm for dynamic decision is described in Fig. 3. The *Priority Phase* is used to remove all the unwanted and ineligible networks from the prospective candidate networks. The *Normal Phase* is used to accommodate user-specific preferences regarding the usage of network interfaces. The user preferences are expressed in terms of weight factors. Finally, the *Decision Phase* is used to select the "Best" network and executing the handoff to the selected network.

A. System Monitor

This module monitor the current battery level of the mobile station and record the user preferences for various networks based on the current battery level, offered bandwidth, usage charges and power consumption by their interface card. These preferences, expressed in terms of weight factors, are passed on to the Network Analysis module to calculate the score function.

B. Network Analysis (NA)

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

$$S_n = f(B_n, P_n, C_n) \tag{1}$$

Here, S_n is the static score for network n.

<div style="border:1px solid black">

Dynamic Decision Process

Priority Phase: (Network Discovery)

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

Normal Phase: (Network Analysis)

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

Decision Phase: (Network Selection and Execution)

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

</div>

Fig. 3 Algorithm for Dynamic Decision Process

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

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

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

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

For our model –

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

Where

w_b is weight factor for *Offered Bandwidth*, w_p is weight factor for *Power Consumption* by network interface and w_c is weight factor for *Usage Cost* of network. $f_{b,i}$, $f_{p,i}$ and $f_{c,i}$ represents the normalized score of interface i for *Offered Bandwidth, Power Consumption and Usage Cost* respectively which are defined as :

$$f_{b,i} = e^{\alpha}_i / e^M \quad , \alpha_i \geq 0 \ \& \ M \geq \alpha_i \qquad (4)$$
$$f_{p,i} = 1/e^{\beta}_i \quad , \beta_i \geq 0 \qquad (5)$$
$$f_{c,i} = 1/e^{\gamma}_i \quad , \gamma_i \geq 0 \qquad (6)$$

The coefficients α_i, β_i, γ_i can be obtained via a lookup table or

well-tuned functions as below:

$$\alpha_i = Min(x_i, M)/M \quad ;M= 2Mbps \qquad (7)$$
$$\beta_i = 2/y_i \quad ; y_i: hours \qquad (8)$$
$$\gamma_i = z_i / 20 \quad ; z_i : Rs./min \qquad (9)$$

Eq. 5 & 6, used the inversed exponential equation for $f_{p,i}$ and $f_{c,i}$ to bound the result to between zero and one (i.e. these functions are normalized) and properly model users preferences. For $f_{b,i}$ a new term M is introduced as the denominator to normalize the function, where M is defined as the maximum link capacity among all available interfaces. Note that, the properties of bandwidth and usage cost/power consumption are opposite (i.e. the more bandwidth the better, whereas lower cost/power consumption is preferred).

C. Network Discovery (ND)

The object of this module is to identify all the Candidate Networks from all the available networks and assign them Priority.

Candidate Network Selection:

A candidate network is the network whose received signal strength is higher than its threshold value and its velocity threshold is greater than the velocity of mobile station.

Let N= $\{n_1,n_2,n_3\ldots\ldots n_k\}$ is the set of available network interfaces.

VT=$\{vt_1,vt_2,vt_3,\ldots\ldots vt_k\}$ is the set of threshold values of velocities for a mobile station for the respective networks.

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

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

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

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

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

Let the MS is currently in network n_i Then

If $RSS_i < rsst_i$ then
 For *all n_j where j ≠ i*
  If *($RSS_j > rsst_j$ and $v_i < vt_j$)* then
 {CN} = {CN} U $\{n_j\}$
 $RssDiff_j = RSS_j - rsst_j$

Priority Assignment:

The priority is based on RssDiff where higher the RssDiff means higher the priority. It is so because higher RssDiff indicate that the MS is more nearer to the BS of that network and hence the MS can stay for more time in the cell of the respective network before asking for another handoff. Thus it

makes possible to reduce the unnecessary handoffs and improve the overall performance of the system. The priory p is assigned to all the networks as below-

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

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

Using above rule based the Network Discovery module select the eligible networks from the all available networks and assign the priority.

D. Dynamic Decision (DD)

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

$$DScore_i = S_i * p_i \qquad (4)$$

Where S_i is the score calculated by the NA module and p_i is the priority decided by the ND module for the ith network.

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

V. SIMULATION

In order to evaluate and analyse the proposed decision model, an application is written in VC++ to simulate a heterogeneous network system where two cellular systems GSM & CDMA and a WLAN form an overlay structure, as shown in Fig. 4. A mobile terminal (MT) with triple network interfaces can move in the cell boundaries of any network during simulation.
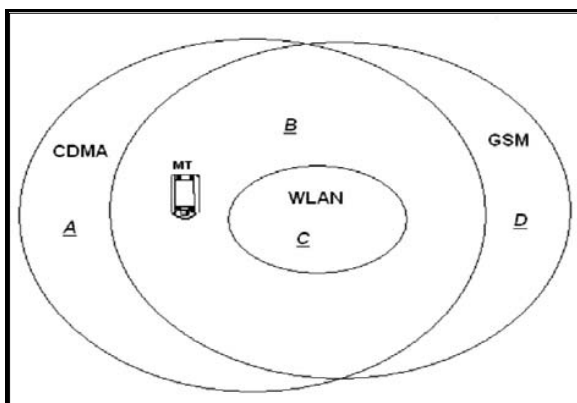

Fig. 4 The Simulation Topology

The mobile terminal MT can be in any one of the regions from A, B, C and D at a moment of time and is able to access the networks as per below:
If the MT is in-
Region A – can access only CDMA network.
Region B – can access CDMA & GSM both.
Region C – can access all WLAN, CDMA & GSM networks.
Region D – can access only GSM network.

The simulation is carried out for all three possible scenarios where the MT can be in WLAN or in CDMA or in GSM network at the start of simulation based on the *assumed parameters* as mentioned in Table I.

While in roaming, the mobile terminal MT monitors the networks as well as system continuously for various parameters but the handoff decision function is executed at a specified *time intervals*, the value of which is provided by the user at the start of simulation.

The simulations are performed for both SDM (i.e. standard decision model, which does not use received signal strength and velocity in decision making) and proposed DDM (Dynamic Decision Model) and The results are carried out for the No. of Handoffs performed with respect to the input user preferences expressed in terms of weight factors Wc,Wb and Wp.

TABLE I
SIMULATION PARAMETERS

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

The results are compared to highlight the reduction in No. of Handoffs and presented using graphs in Fig. 5 to Fig. 7. Fig. 5 shows the no. of handoffs performed when the MT is initially in WLAN network and weight factor for usage cost and offered bandwidth are equal while weight factor for power consumption is varying; similarly for Fig. 6 and Fig. 7.
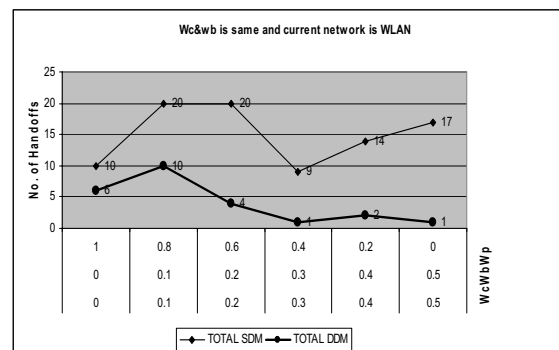

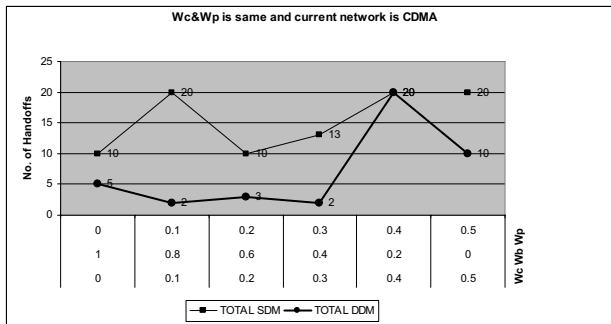Fig. 5 No. of handoff versus weight factor when Wc=Wb

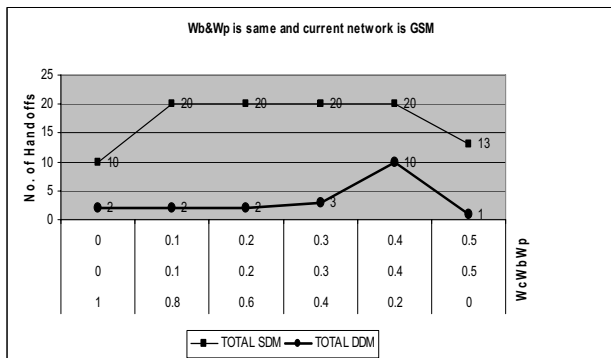Fig. 6 No. of handoff versus weight factor when Wc=Wp

Fig. 7 No. of handoff versus weight factor when Wb=Wp

The results shows that the no. of handoffs performed in DDM is reduced by 50% to 60% from the handoffs performed using SDM.

VI. FUTURE WORK

This paper present a rule based approach to relate the Received signal strength (RSS) of a network and the velocity of the mobile station with the decision making for vertical handoff. However, further research can be conducted to develop a function which can relate directly the RSS with the velocity. So that the function can be utilized with other factors in making a decision for vertical handoff.

VII. CONCLUSION

This paper proposes, develop and simulate the *Dynamic Decision Model,* for performing the vertical handoffs to the "Best" interface at the "best" time moment, successfully and efficiently.

The *Dynamic Decision Model* for VHO adopts a three phase approach comprising Priority phase, Normal phase and Decision phase. The P*riority Phase*, discover all available networks, filter out ineligible networks based on RSS & velocity and then assign the priorities to all eligible candidate networks using the difference between RSS and its threshold value RSST where Higher the difference, higher the priority. The *Normal phase* record the system information and user preferences for offered bandwidth, power consumption, and network usage in terms of respective weight factors w_b, w_p,& w_c where higher the preference, higher the value of weight

factor**.** It then calculates a cost function for each candidate network**.** Finally, the *Decision phase* calculates a Score function, by multiplying the priority from priority phase and cost function from normal phase, for each candidate network. It then select a network having the highest value of score function as "Best" network to handoff and transfer all the current transmissions to selected network if different from the current network.

This Dynamic Decision Model is simple and applicable with any handoff Implementation techniques. However, this model is more suitable to perform "Soft Vertical Handoffs" using application layer approaches like USHA.

REFERENCES

[1] M. Angermann and J. Kammann, "*Cost Metrics for Decision Problem In Wireless Ad Hoc Networking,*" IEEE CAS Workshop on Wireless Communications and Networking, 2002.
[2] L. Chen, T. Sun, B. Chen, V. Rajendran and M.Gerla, "A smart decision Model for vertical handoff", The 4th Int'l Workshop on Wireless Internet and Reconfigurability (ANWIRE'04) (May 2004).
[3] L.-J. Chen, T. Sun and M. Gerla,"USHA: simple and practical seamless vertical handoff solution", IEEE CCNC 2006.
[4] Mark Stemm, and Randy H. Katz. "Vertical Handoffs in Wireless Overlay Networks," ACM MONET, 1998.
[5] H.J. Wang, R. H. Katz, and J. Giese, "Policy-Enabled Handoffs across Heterogeneous Wireless Networks," Proc. of ACM WMCSA, 1999.
[6] Hasswa, A.; Nasser, N.; Hossanein,H "*Generic vertical handoff decision function for heterogeneous wireless*" Second IFIP International Conference on Wireless and Optical Communications Networks, 2005. WOCN 2005.
[7] Shen,W.;Zeng,Q.-A. "A Novel Decision Strategy of Vertical Handoff in Overlay Wireless Networks" Fifth IEEE International Symposium on Network Computing and Applications, 2006.
[8] Qingyang Song, Abbas Jamalipour, "A Time-Adaptive Vertical Handoff Decision Scheme in Wireless Overlay Networks", IEEE 17th International Symposium on Personal, Indoor and Mobile Radio Communications, 2006.
[9] Min Liu; Zhong-Cheng Li; Xiao-Bing Guo; Hong-Yon Lach "*Design and Evaluation of Vertical Handoff Decision Algorithm in Heterogeneous Wireless Networks*" 14th IEEE InternationalConference on Networks, 2006. ICON '06. Volume:2, Sept. 2006.
[10] Stevens-Navarro, E.; Wong, V.W.S, "A Vertical Handoff Decision Algorithm for Heterogeneous WirelessNetworks" IEEE Wireless Communications and Networking Conference, 2007.WCNC 2007.
[11] Tawil, R.; Salazar, O.; Pujolle,G.; Demerjian,J , " *A Decision Scheme for Vertical Handoff in Overlay Wireless Networks*" 4th International Conference on Innovations in Information Technology, 2007. Innovations '07. 18-20Nov.2007.
[12] Ahmad, S.Z.; Akbar, M.S.; Qadir, M.A "*A Cross-Layer Vertical Handover Decision Model for Heterogeneous Wireless Networks*" 4th International Conference on Innovations in Information Technology, 2007.Innovations'07. 18-20 Nov. 2007 Page(s):441-445.
[13] Ahmed H.zahran, Ben Liang, Aladdin Saleh, "*Signal Threshold Adaptation for Vertica handoff in heterogeneous wireless networks*", Mobile Network Application (2006), Springer science.

Pramod Goyal received the B.E degree in Computer Engineering from University of Rajasthan, Jaipur, in 1996. He is lecturer in Department of Training & Technical Education, Govt. of Delhi and currently pursuing his ME at Delhi College of Engineering, Delhi.