# A Comparison of Different Vertical Handoff Algorithms between WLAN and Cellular Networks

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## Abstract

Today, the advent of heterogeneous wireless networks is revolutionizing the telecommunications industry. As IP-based wireless networking increases in popularity, handoff issues must be taken into consideration. When a user switches between networks with different technologies, many issues have to be considered in order to increase the efficiency of the network during vertical handoff. In this paper, several algorithms for optimizing vertical handoff between WLAN and the cellular networks are discussed. In each of these algorithms, specific factors were considered and then a comparison made in order to see the effect of each factor on vertical handoff. It was found that when both received signal strength and service history information are taken into account in algorithm design, the number of handoffs would be reduced and the throughput of the network increased.

## Introduction

Heterogeneous wireless networks consist of different Wireless Area Networks (WLAN), various cellular networks, and many other networks with different technologies. The most popular networks are WLAN and cellular networks. Recently, the use of WLAN in areas such as airports, hotels, and school campuses has increased.

On the other hand, although cellular networks such as 4G networks support a higher degree of mobility and a wider area of coverage, they offer guaranteed quality of service in data transmission at the lower data rate. The complementary features of these two networks, WLAN and cellular networks make their integration highly desirable. One of the most important issues in heterogeneous wireless networks is vertical handoff, which occurs when a user switches between two different network interfaces with different technologies. For example, if a mobile node leaves the 802.11b network domain and enters the 802.16 network domain, it is called vertical handoff. Many issues have to be accounted for in order to have an effective vertical handoff.

## Classification of Vertical Handoff Algorithms (VHD)

Because of the popularity of integrated networks and the associated problems of vertical handover issues, various strategies have been developed for optimizing vertical handoff and researchers have considered many factors and have offered several algorithms. The following list classifies these algorithms (see also Figure 1).

### Vertical Handoff Algorithms

1. Smart Decision Model using a score function
2. Algorithm considering Service History information
3. Vertical handoff scheme between mobile WiMax and cellular networks based on the Loosely Integration Model
4. Novel vertical handover scheme for Integrated WLAN and Cellular Networks

*Received Signal Strength (RSS) Based VHD Algorithm*

1. An Adaptive Lifetime-based heuristic
2. An RSS Threshold-Based Dynamic heuristic
3. A Traveling-Distance Prediction-Based heuristic

*Bandwidth-Based VHD Algorithms*

1. A QoS-Based heuristic
2. A Wrong Decision Probability (WDP) Prediction-Based heuristic

*Cost-Function-Based VHD Algorithms*

1. A multiservice-based heuristic
2. A Cost-Function-Based heuristic with Normalization and Weight Distributions
3. A Weighted Function-Based heuristic

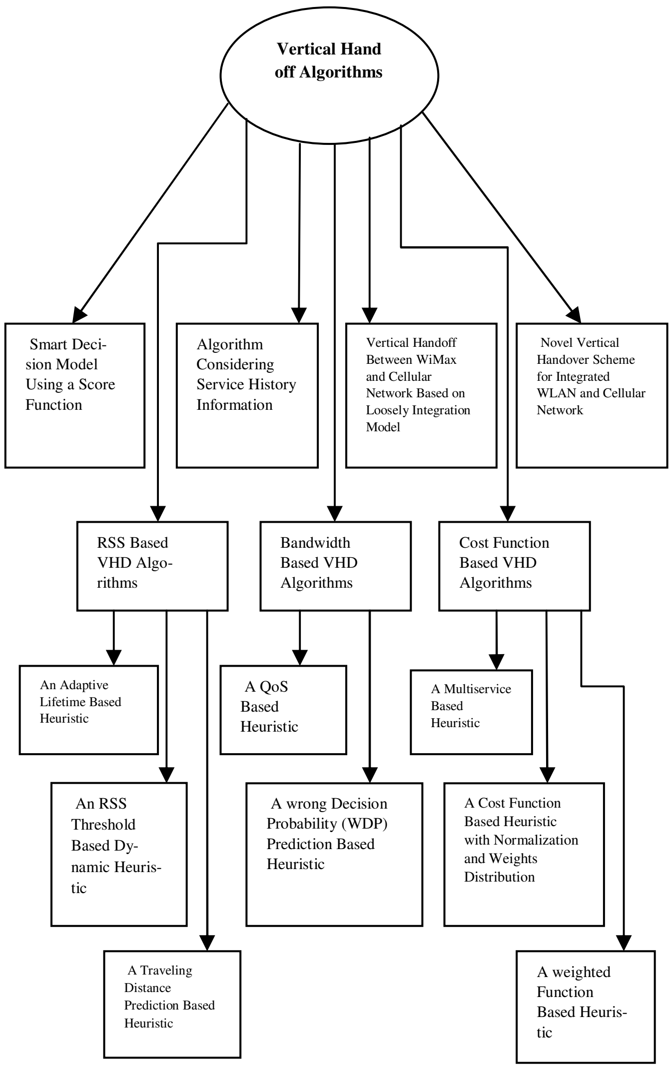


**Figure 1. Classification of Vertical Handoff Algorithms**

# A Smart Decision Model for Vertical Handoff

A Universal Seamless Handoff Architecture (USHA), which was based on the fact that the handoff happens only under certain conditions, was previously proposed by researchers [1]. This algorithm was further developed in order to solve the smart decision problems [2]. The design of a USHA was based on the fact that the handoff occurs only in specific circumstances. It happens on overlaid networks with multiple internet access methods. In this design, the best network would be chosen with zero waiting time. The main factor in this design was based on overlapping the coverage for different kinds of access methods. In the case where the coverage fails to overlap, the USHA may lose the connection with the upper layer [2].

In this architecture, there is a Handoff Server (HS) which is connected to several mobile hosts via an IP tunnel. All of the applications in all communications layers are connected to the tunnel interface. All of the packets are also encapsulated for transmission through this channel and a UDP protocol (User Datagram Protocol) is used for transmissions. In order to maintain the connectivity between the Mobile Host (MH) and HS, there should be two sets of addresses at both ends of the IP channel, one for the HS and the other for the MH. After the handoff occurs, since the location has changed, the MH should inform the HS about the new address in order to continue the connection. The UDP protocol prevents the IP channel from resetting after handoff occurs [2].

This algorithm was further developed in order to add the smart decision model in which a handoff will occur at the appropriate moment and to the most appropriate network [2]. The proposed design consists of four parts: A Handoff Executor (HE), Smart Decision (SD), Device Monitor (DM) and System Monitor (SM). The DM is responsible for monitoring the status of each network; the SM reports the system information; the SD provides a list of all user interfaces along with the information provided by the DM and applies a score function for calculating the score for each wireless interface; and, the SM identifies the best network for the handoff. The HE performs the handoff to the target network. This model is simple and is able to perform the handover to the best network at the best time since it is able to make a smart decision based on different parameters such as link capacity, power consumption, and link cost [2].

# A QoS-Aware Vertical Handoff Algorithm Based on Service History Information

In distributed VHO (Vertical Hand Off) decision algorithms, all of the users choose the target network simultaneously, ignoring each other. Several problems arise in this design, one of which might be experiencing high congestion by blindly choosing a network which cannot provide the quality of service for the users and may cause handoff call drops and handoff to other networks as well [3].

For optimizing these algorithms, a remedy was introduced by researchers in which the service history of user traffic was considered and was added to the VHO algorithms [3]. Through the introduction of this new architecture, the unstable handoff decisions were alleviated and the quality of the service was improved. Two parameters were considered from service history information for designing this algorithm [3]:

First, $t_0^s$ is the service time for network. This time is equivalent to the amount of time since the last handoff. It is clear that the larger this number, the more efficient the system.

Second, $t_i^F$ (i ≠ 0) is the time calculated from the time when the last handoff was dropped. If this time is small, it means that the system experienced more dropped calls. Therefore, for improving system functionality, this number should be large. From all of the information stated above, it is obvious that if the maximum effective time of history information, $T_c$, is small, the user should be kept in the current network to reduce the number of dropped calls [4]. The proposed evaluation function for this architecture is expressed as:

$$E_i^h(t_i^s) = \begin{cases} \exp(-t_i^s) \ if\ i = 0, 0 < t_i^s < Tc \\ 0\ otherwise \end{cases} \qquad (1)$$

$$E_i^h(t_i^F) = \begin{cases} -\exp(-t_i^F) \ if\ i \neq 0, 0 < t_i^F < Tc \\ 0\ otherwise \end{cases} \qquad (2)$$

where $T_c$ is the maximum effective time of history information and can be set differently $t_i^s$ for a $t_i^F$ . This algorithm improves the performance by reducing the number of handoffs, thereby decreasing the probability of a handoff occurring, as well as reducing the cost [3].

## Vertical Handoff Scheme between Mobile WiMax and Cellular Networks Based on the Loosely Integration Model

Another algorithm for vertical handoff between Mobile WiMax and cellular networks was proposed which is based on the Loosely Integration Model [5]. In this model, WLAN and 3G networks exist independently and provide autonomous services. For authentication and accounting for roaming services, a gateway was added to this incorporative model; for mobility between WLAN and 3G networks, this model also uses a mobile IP. One of the advantages of this model is that it can easily be adapted to existing communications and reduces the effort in developing new standards [5].

The Smoothly Integration Scheme algorithm has an architecture similar to the Loosely Integration Model but only an IWG (Interworking Gateway) was added for interworking between Mobile WiMax and CDMA. The IWG helps by using an Extended Fast Handoff scheme in CDMA packets, which provides a gateway function for protocol adaptation. In the Fast Handoff scheme, the serving PDSN (Packet Data Serving Node) sends traffic to a target PDSN by setting up a tunnel. This traffic is forwarded to other mobile nodes by the target PDSN. In this method, the packet loss is minimized since the service anchor point is not changed [5].

## A Novel Vertical Handover Scheme for Integrated WLAN and Cellular Wireless Networks

A novel vertical handover scheme for integrated WLAN and cellular wireless networks was proposed in which WLAN is overlaid within the coverage area of the cellular network [6]. There is one access point for the WLAN as well as one base station for the cellular network. A Crossover switch connects the access point and the base station. If the user starts communication with the access points, it is considered to be connected to the WLAN. However, if the packet exchange is through base stations, a user is considered to be attached to the cellular network.

The Crossover switch can decide to handover a user from one network to another and would then also transmit subsequent downlink packets to the new access point or base station. This algorithm aims to optimize system utilization without considering packet delay requirements. Two strategies have been defined in order to achieve the objective: The first one is performing unconditional handover when a mobile node is moving out of WLAN coverage and the second one when the mobile node is entering the WLAN coverage. These two conditions are called imperative and alternative, respectively [6].

An unconditional imperative handover will be executed if a user's RSS (Received Signal Strength) is lower than a given threshold, while an alternative handover occurs when a certain number of consecutive handover requests are received by the access point of WLAN from the user. The number of these requests depends on the user's traveling speed and current load of cellular networks. This algorithm can support a larger user arrival rate without dealing with a packet delay violation ratio as well as reducing the number of handovers by 10% [6].

## RSS-Based VHD Algorithms: An Adaptive Lifetime-Based Handover Heuristic

For handoffs between 3G networks and WLAN, an algorithm was proposed in which a lifetime metric was considered. This shows the application-specific time period in which a user can still get services from WLAN [7]. The algorithm involves two scenarios which are described as follows:

First Scenario:
A handover from WLAN to the 3G network will happen if the RSS average of the WLAN connection is less than the predefined threshold and if the lifetime is less than or equal to the handover delay [7], [8].

Second Scenario:
A handover is initiated if a mobile terminal moves from a 3G network to a WLAN network. The handover will be triggered if sufficient bandwidth is available on the WLAN network and if the threshold of the 3G network falls below the average RSS measurement of the WLAN signal [7], [8].

In this algorithm, the author achieved many benefits in handover between these aforementioned networks. By using the lifetime metric, the number of extra handoffs was decreased and throughput of the network was dramatically increased. On the other hand, increasing the lifetime caused an increase in the packet delay, which is noted as a disadvantage of this algorithm. For solving this problem, the ASST (Application Signal Strength Threshold) was adjusted based on different parameters such as delay thresholds, mobile terminal velocities, handover signaling costs, and packet delay penalties [7], [8].

## An RSS Threshold-Based Dynamic Heuristic

In this algorithm, a dynamic RSS threshold ($S_{dth}$) is defined when a mobile terminal is connected to a WLAN access point, and is used for a handoff decision from WLAN to 3G through comparison of the current RSS and $S_{dth}$. By using $S_{dth}$ in this algorithm, the number of false handoffs will be reduced and the handoff failure will be kept below a certain limit, while the number of superfluous handoffs will remain the same [8], [9]. $S_{dth}$ can be calculated from [9]:

$$S_{dth} = RSS_{\min} + 10\beta \log 10\left(\frac{d}{d - L_{BA}}\right) + \varepsilon \qquad (3)$$

where $RSS_{min}$ (in dBm) is the minimum RSS needed for the mobile terminal to communicate with an access point; $B$ is the path loss coefficient; and $d$ is the side length of the WLAN cell in meters. In this study, the assumption was that WLAN cells would have a hexagonal shape, LBA would be the shortest distance between the point at which handover is initiated and the WLAN boundary, and ε (in dB) would be a zero-mean Gaussian random variable with a standard deviation. This represents the statistical variation in RSS caused by shadowing [8], [9].

The distance, $L_{BA}$ , varies with the desired handover failure probability, $p_f$, the velocity of the mobile terminal, v, and the handover delay from WLAN to 3G, which is shown as $\tau$. LBA is calculated as follows:

$$L_{BA} = [\tau^2 v^2 + d^2 (p_f - 2 + 2\sqrt{1 - p_f}]^{\frac{1}{2}} \qquad (4)$$

In this algorithm, the authors assumed that the failure probability from 3G to WLAN would be zero, so the handoff can happen anytime a mobile terminal enters WLAN coverage [8], [9]. One of the advantages of this algorithm is that when a mobile terminal's traveling time inside a WLAN cell is less than the handoff delay, then the handoff may result in a waste of network resources [8], [9].

## A Traveling-Distance Prediction-Based Heuristic

This is another RSS-based algorithm in which the authors considered the time it takes for a mobile terminal to travel via a WLAN cell ($t_{WLAN}$) in order to reduce the number of unnecessary handoffs. In this design, a handoff will occur when the traveling time is greater than the time threshold ($T_{WLAN}$). The traveling time ($t_{WLAN}$) is calculated as follows [10]:

$$t_{WLAN} = \frac{R^2 - I_{os}{}^2 + v^2 (t_s - t_{in})^2}{v^2 (t_s - t_{in})} \qquad (5)$$

While this algorithm reduces the number of extra handoffs and minimizes handoff failures, the mobile terminal's traveling time is still less than the handover delay which causes loss of network resources [8], [10].

# Bandwidth-Based VHD Algorithms: A QoS-Based Heuristic

Another algorithm for handover from WLAN to WWAN (Wireless Wide Area Network) was proposed in which the remaining bandwidth, the state of the mobile terminal, and the user service requirements are taken into account [11]. In this algorithm, two scenarios are described: Handover from WLAN to WWAN, and WWAN to WLAN [8], [11].

In the first scenario, for handover decisions, while the mobile terminal is connected to WLAN, the measured RSS should fall below a threshold ($RSS_{T1}$). Handover will be given to the best network if the mobile terminal is in the idle state, otherwise the handoff decision is based on user application type [8], [11]. Here, two types of applications are taken into consideration.

1. Delay-sensitive applications
   For this type of application, a handover occurs if there is insufficient bandwidth available on the WLAN to serve the user, while WWAN provides available bandwidth for the user's application.
2. Delay-tolerant applications
   A handover happens if WWAN provides higher bandwidth for the user than the WLAN.

In this case, the remaining bandwidth should be calculated for the WLAN, as follows, in order to take the handoff decision. Remaining bandwidth = Throughput × (1-α×Channel Utilization) × (1-Packet loss rate). Throughput is the throughput that can be shared among mobile terminals in the WLAN. Channel utilization is the percentage of time that the access point, by using a carrier sense mechanism, senses the medium as busy. α is a factor that reflects IEEE 802.11 MAC overhead and was set to 1.25 in this study. Finally, packet loss rate is that part of the transmitted medium access control (MAC) protocol data units (MPDUs) which require retransmission, or are discarded as packets that are not delivered. The values of channel utilization and packet loss rate are obtained from the information in the beacon frame carrying the QoS basic service set (QBSS) load, which is sent by an access point [8], [11].

In the second scenario, a handover occurs from WWAN to WLAN if the RSS in the WWAN is less than the threshold ($RSS_{T2}$) [8], [11].

# A Wrong Decision Probability Algorithm (WDP) Prediction-Based Heuristic

A WDP algorithm is another vertical handoff algorithm which is based on the probability of unnecessary and missing handovers [12]. If you consider two kinds of networks, x and y, as well as the bandwidth associated with these networks, $B_x$ and $B_y$, an unnecessary handover occurs when a handoff is performed from network x to network y, while the available bandwidth in network x ($B_x$) is less than the available bandwidth in network y ($B_y$). On the other hand, a missing handover occurs when a mobile terminal in network x should perform a handover to network y because of lack of available bandwidth in network x, yet maintains its connectivity to network x [8], [12].

A handover from network x to network y is initiated if

$$P_r < \rho\times L_0 \text{ or } b_y\text{-}b_x \leq L \tag{6}$$

where $P_r$ is the unnecessary handover probability; ρ is the traffic load of network x; $L_0$ = 0.001; and $L$ is bandwidth threshold [12].

The proposed algorithm has several advantages: it reduces the Wrong Decision Probability (WDP) and balances the traffic load. However, it does not consider RSS, which is a main factor in handoff decisions. Received signal strength is a main factor in every handover; however, a handover to a network with high bandwidth but weak signal strength is undesirable [8], [12].

# Cost-Function-Based VHD Algorithms: A Multiservice-Based Heuristic

A cost-function-based algorithm is another VHO algorithm which works using a cost function [13]. The algorithm gives priority to active applications that need to perform a handover to a target network. Therefore, the service with the highest priority is selected On the other hand, the cost of a series of target networks will be calculated after which the handover would occur between the application with the highest priority and the network with the lowest cost [8], [13], [14]. This algorithm provides user applications with reduced blocking probability. It also satisfies more user requests, though there is no mention of the manner in which the QoS factors are weighted and normalized. This algorithm was further developed in order to consider normalization and weight-distribution methods [8], [13- 15].

## A Cost-Function-Based Heuristic with Normalization and Weight Distribution

In this algorithm, by calculating the network quality factor, the performance of a target handover can be evaluated [16]. Furthermore, if the handover is necessary, then the network parameters will be collected before the weight and quality factor are calculated. Then, if the current quality is less than the candidate quality, the handover will be initiated [8], [16]. In order to avoid superfluous handovers, a metric called a handover necessity estimator was introduced. The network quality factor is calculated as follows [8], [16]:

$$Q_i = W_c C_i + W_s S_i + W_p P_i + W_d D_i + W_f F_i \qquad (7)$$

where $Q_i$ is the quality factor of network i; $C_i$ is cost of service; $S_i$ is security; $P_i$ is power consumption; $D_i$ are the network conditions; and, $F_i$ is network performance. Here, $w_c$, $w_s$, $w_p$, $w_d$, and $w_f$ are the weights for these network parameters. Since each network parameter has a different unit, a normalization procedure was used [16]. Advantages of this algorithm include increased throughput of the system and user satisfaction. However, this algorithm does not provide information for estimating security and interference levels [8], [16].

## A Weighted Function-Based Heuristic

A Weighted Function-Based Heuristic is another algorithm which was designed for VHO issues [17]. Despite other algorithms in which the mobile terminal was responsible for the VHD calculation, this algorithm VHD calculation is done in the visited network. The quality of network ($Q_i$) will be calculated as follows:

$$Q_i = W_b B_i + W_d D + W_c C \qquad (8)$$

where B, D, and C are bandwidth, dropping probability, and cost of services, respectively. And $W_b$, $W_d$, and $W_c$ are their weights where

$$W_b + W_d + W_c = 1 \qquad (9)$$

In this algorithm, the network with the highest Qi will be selected as the target network for handover. As a result, the handover delay will be decreased, the handover blocking rate will be lowered, and the throughput will be increased. However, since there should be extended communication between the mobile terminal and the access point of the visited network, there might be additional delay and load when there is large number of mobile terminals [8], [17].

# Comparison

In the Smart-Decision algorithm, based on several network parameters such as link capacity, power consumption, and link cost, the authors proposed a model to intelligently decide which network to choose in order to execute vertical handoff. By considering many factors, this algorithm decides which network is the best for executing a handover and helps to overcome many problems that may arise in the execution of the handoff.

In this algorithm, based on system history information, the number of handoffs, the values of handoff probability, and the cost were decreased. This algorithm also works better in more complicated networks. In the Vertical Handoff Scheme between Mobile WiMax and Cellular Networks, the level of packet loss is minimized. In the Novel Vertical Handover Scheme between WLAN and Cellular Networks, the total number of handovers was reduced; and, by using $L_{preset}$ and monitoring the load in the network, the number of unnecessary handovers was reduced. Moreover, this algorithm can support a larger user arrival rate without dealing with the packet delay violation ratio.

An Adaptive Lifetime-Based Handover heuristic algorithm could reduce the number of unnecessary handoffs as well as increase the throughput of the network by considering a lifetime metric. However, if there is an increase in the lifetime, the delay in the network will increase, so this algorithm may not work properly for delay-sensitive applications.

The RSS Threshold-Based Dynamic heuristic reduces the number of false handovers and keeps the handover failures below a certain limit. However, the disadvantages of this algorithm are that the number of extra handoffs will remain the same and, if the mobile station's traveling time inside a cell is less than handover delay, there is waste of network resources.

The Traveling Distance Prediction-Based heuristic reduces the number of handover failures, superfluous handovers, and connection breakdown. However, sampling and averaging RSS will increase the handover delay. Furthermore, the mobile terminal's traveling time is still less than the handover delay which causes loss of network resources. The QoS-Based heuristic, by considering bandwidth, increased the throughput of the network. This algorithm works well for delay-sensitive applications since it decreases the delay by considering the application type.

In the Wrong Decision Probability Algorithm, the RSS was not considered but this algorithm reduces the wrong decision probability while balancing the traffic load. Since this algorithm does not consider the RSS, it is not efficient because it may cause several breakdowns in the network. The Multiservice-Based heuristic reduces the blocking probability. A Cost-Function-Based heuristic with Normalization and Weight Distribution algorithm provides high throughput for the system, but some of the parameters such as security and interference level are difficult to measure in the network. The Weighted-Function-Based heuristic provides short handover decision delays, low handover blocking rates, and high throughput. However, it may cause extra delay and load to the network.

# Conclusion

Considering all of the algorithms discussed above, it is obvious that all of them have advantages and disadvantages that may affect the performance of the network.

Most of these algorithms, such as the Weighted Function-Based heuristic and the Traveling-Distance-Based Prediction algorithm have some advantages such as low handover blocking rates and reduced number of handover failures, respectively. However, those impose extra delay to the network. Of all the algorithms, the QoS Aware Vertical Handoff algorithm based on Service History Information reduces the number of handoffs, reduces handover failure probability, and increases throughput of the network without imposing any superfluous delay to the network. This indicates that considering service history information in designing VHO algorithms can benefit network a lot. Moreover, RSS-based algorithms all have one benefit in common, which is decreasing the number of handoffs. Therefore, it can be concluded that by designing an algorithm to consider both service history information and the RSS, many advantages could be obtained for vertical handoff between WLAN and the Cellular Network. This hypothesis arose from the comparison part; however, future results may vary based on different parameters, and different real network design. Therefore, the simulation and proof of the stated hypothesis will be addressed in future studies.

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