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# Vertical Handover Decision Processes for Fourth Generation Heterogeneous Wireless Networks

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**ABSTRACT —** ***The increased growth in consumer demand for seamless access to communication services anywhere and anytime is inevitably driving an accelerated technological development towards the integration of an assortment of wireless network technologies – nowadays referred to as 'Fourth Generation (4G) Wireless Systems'. In a typical 4G networking scenario, mobile terminals (MTs) with multiple interfaces are able to choose the most pertinent access links among the accessible substitutes [i.e. IEEE 802.11 WLANs, IEEE 802.16 WiMAX, satellite systems, bluetooth, etc. in addition to the traditional cellular telephony networks]. Thus to achieve seamless mobility and the requisite Quality of Service (QoS) in such a diverse environment, efficient 'Vertical Handover Decision (VHD)' algorithms needs to be designed in order to avert any degradation of services, reduction in throughput, increase in blocking probability and packet loss caused due to the unnecessary handovers, handover failures and connection breakdowns. This paper intends to present a comprehensive survey of VHD algorithms designed to satisfy these requirements. To offer a systematic comparison and thus to assess the tradeoffs between their complexity of implementation and efficiency, our study has categorized algorithms into various groups based on the main handover decision criterion used. The survey revealed that the currently proposed VHD algorithms either lacked a comprehensive consideration of several network parameters or studies' reporting these problems lacks sufficient detail for implementation.***

**Keywords —** Heterogeneous Wireless Networks, 4G, Vertical Handovers, Vertical Handover Decision Algorithms.

## 1. INTRODUCTION

Communication technologies have became an integral part of people's daily life and wireless communication market has matured swiftly. Driven by the increasing demand – today, the wireless communication technologies have advanced through First Generation (1G) of early 1980s to Second Generation (2G) in 1991, to the Second and a Half Generation (2.5G) in 1999, to the Third Generation (3G) in 2003, and still further progressing towards 4G [Table I illustrates the salient features of each of these generations by comparing their service type, representative standard, radio frequency, bandwidth, multi - address techniques and core network]. In contrast to previous generations, 3G technology assisted network operators to offer users with a greater bandwidth, security and reliability; thus making it more suitable for certain advanced applications such as mobile e-commerce, video-conferencing, video-on-demand, location-sensitive services (i.e. mobile programs to search for bars or restaurants), customized personal information services, etc. However, its major disadvantage lies in its associated high costs for both the network operators and end users due to the continuous upgradation of cellular infrastructure and soaring spectrum-license costs [1-2].

The Beyond Third Generation (B3G) wireless networks are expected to provide users with convenient global information access competences and personalized wireless communication services [3]. Their architecture aims to integrate an assortment of heterogeneous wireless networks over an Internet Protocol (IP) backbone. The recently sanctioned / ratified IEEE 802.21 Media Independent Handover standard intends to support the seamless roaming among various wireless access technologies [comprising of GSM, UMTS, WLAN, WiMAX and Bluetooth] through different handover mechanisms. Some of the leading world's carriers have already started working on this approach. In Jan. 2009, the 4G network 'CLEAR' was launched through the collaboration of Clearwire and Intel in Portland, Oregon, USA. Similarly, major carriers such as AT&T are in process of converting their existing networks into 4G using a successor of UMTS – 3rd Generation Partnership Project (3GPP) Long Term Evaluation (LTE) standards.

**Table 1:** Salient Features of Different Generations of Wireless Communication Technologies

| GENERATIONS / FEATURES | 1G | 2G | 2.5G | 3G | 4G |
|---|---|---|---|---|---|
| SERVICE TYPE | Analog Voice | Digital Voice | Higher Capacity, Packetized Data | Higher Capacity, Broadband Data Upto 2Mbps | Complete IP Based, Speed: Hundreds of MBs |
| REPRESENTATIVE STANDARD | AMPS, TACS | GSM, I-Mode | GPRS, TDMA, HSCSD, EDGE | IMT-2000 (UMTS, WCDMA, CDMA 2000) | Single Standard |
| RADIO FREQUENCY (HZ) | 400M ~ 800M | 800M ~ 900M 1800M ~ 1900M | | 2G | 2.6G |
| DATA BANDWIDTH (BPS) | 2.4K ~ 30K | 9.6K ~ 14.4K | 171K ~ 384K | 2M ~ 5M | 200M |
| MULTI-ADDRESS TECHNIQUES | FDMA | TDMA, CDMA | | CDMA | OFDM |
| CORE NETWORK | PSTN | PSTN | PSTN, Packet Network | Packet Network | Internet |

## 2. OVERVIEW OF VERTICAL HANDOVER PROCESS

Handover is process of maintaining a user's active sessions, as MT migrates from air interface served by one base station (BS) to air interface served by another BS [also referred to as *'point of attachment' ~ PoA*]. Depending on the access network that each PoA belongs to, handover can be either *'Horizontal'* or *'Vertical'* [4-5]. Fig. 1 illustrates a graphical representation of these handover classifications.

- *Horizontal [or an intra-system] handover takes place among the PoAs supporting same network technology, i.e., between any two geographically neighboring IEEE 802.11 access points (APs).*
- *Vertical [or an inter-system] handover occurs among the PoAs supporting different network technologies, i.e. between IEEE 802.11 AP and 3G cellular network.*

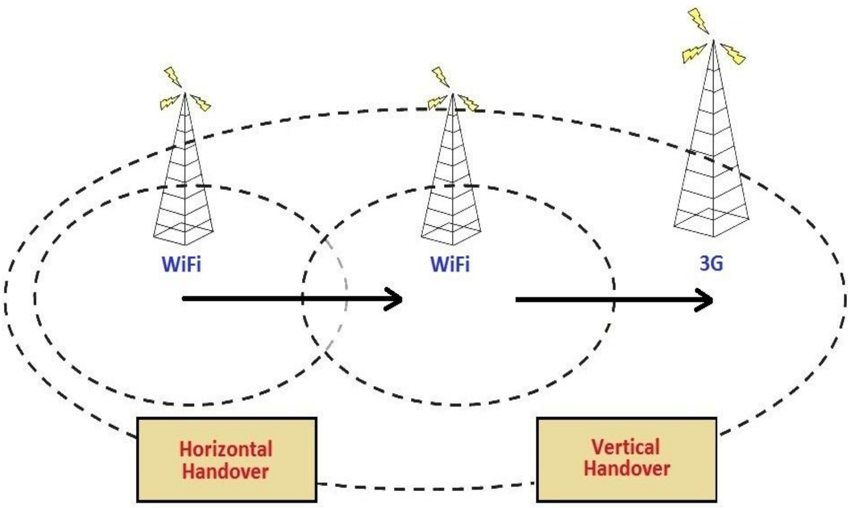


**Figure 1:** Graphical Illustration of Horizontal and Vertical Handovers

A vertical handover is executed across heterogeneous cells of access systems, which differ(s) in several characteristics, i.e. bandwidth, data rate, frequency of operation, etc., consequently making its implementation quite challenling as compared to horizontal handover. Vertical handovers are further categorized as being either *'Upward'* or *'Downward'* [6-7].

- *Upward vertical handover is a handover to a wireless overlay with a larger cell size and (generally) lower bandwidth per unit area. This makes the MT disconnect from a network providing faster but smaller coverage to new network providing slower but broader coverage.*
- *Downward vertical handover is a handover to wireless overlay with a smaller cell size and (generally) higher bandwidth per unit area. This makes the MT disconnect from a network providing slower but broder coverage to new network providing limited coverage with higher access speed.*

## *2.1 Vertical Handover Process (VHO)*

The vertical handover process can be segmented into three stages: *Network Discovery, Handover Decision and Handover Triggering [8].*

- *Network Discovery* – is the process wherein a MT with multiple interfaces searches for the accessible wireless networks. This is acheived by activating all the critical interfaces of an MT, so that the service advertisments broadcasted by different wireless technologies can be heard. However, keeping interfaces continously active consume power even without receiving / sending some packets. The ideal approach is though to periodically activate the MT interfaces, so as to continously receive the service advertisements. Discovery time should also be kept low, so that MT can benefit faster from the new wireless networks. As the activating frequency directly influences system's discovery time; the MT activating interfaces with a higher frequency may discovers the reachable network much more quickly, but its battery may consumes out soon. Therefore, there always exists a tradeoff between the power efficiency and system's discovery time [9].
- *Handover Decision* – is the competence to decide about the targeted PoA and the exact time of handover. This decision depends on several issues / policies pertient to network to which a MT is already connected and to the one that it is going to handover, i.e. (network) available bandwidth, power consumption, monetary costs, QoS, security, user preferences, etc. VHD schemes generally comprise of three close integrated processes: *Handover Necessity Estimation, Handover Target Selection, and Handover Triggering Condition Estimation* [10]. Fig. 2 depicts the detailed steps involved in a VHD algorithm [1].
  - ✓ *Handover Necessity Estimation (HNE) ascertains that whether a particular handover is necessary to an available network.*
  - ✓ *Handover Target Selection (HTS) selects the best possible network among the available candidates based on a fixed set of criteria.*
  - ✓ *Handover Triggering Condition Estimation (HTCE) determines right / exact moment in order to commence the handover out of the currently connected network.*
- *Handover Triggering* – requires transfer of data packets to a new wireless network, so as to re-route the user's connection path to selected PoA. Since 4G hetrogenous networks operates in multi-network / multi-standards environment, the transfer of packets to a new network is augmented with contextual information. This is done so as to minimize delay in re-establishing MT traffic flows. However, if the context transfer delay is as large as having the impact of a complete re-establishment, or large enough to increase the overall handover call drop rate, the advantages of context transfer are lost [10].

## *2.2 Criteria for Vertical Handover Decisions*

Several parameters have been previously discussed in the literature for use in VHD algorithms [2, 11] and are briefly explained as follows:

- *Received Signal Strength (RSS)* – is one of the most critical criteria for the VHD algorithms. RSS is easy to measure and is closely related to the service quality. There always exist(s) a close relationship between RSS readings, and the distance between MT and its PoA.
- *Network Connection Time* – refers to the duration for which MT remain connected to a particular network. Determining network connection time is critical for choosing the exact moment for initiating a handover, so as to maintain the QoS at a satisfactory level.
- *Handover Latency* – for MT is depicted as the 'time' that elapsed between the last packets received via the old access router and arrival of the first packet along the new access router.
- *Available Bandwidth* – is a measure of available data communication resources in bit/s.
- *Power Consumption* – becomes crucial if MTs battery is low. In such sort of situations, handover is preferable to PoA that may help extend battery's life.

- *Monetary Costs* – needs to be taken into consideration for VHD decisions, as charging policy (/ies) could be varying among different networks service.
- *Security* – is critical for the applications demanding confidentiality and integrity of transmitted data. Thus, a network with higher security may be chosen over the network with lower level of data security.
- *User Preferences* – towards an access network could lead to the selection of one type of network over the other candidates.

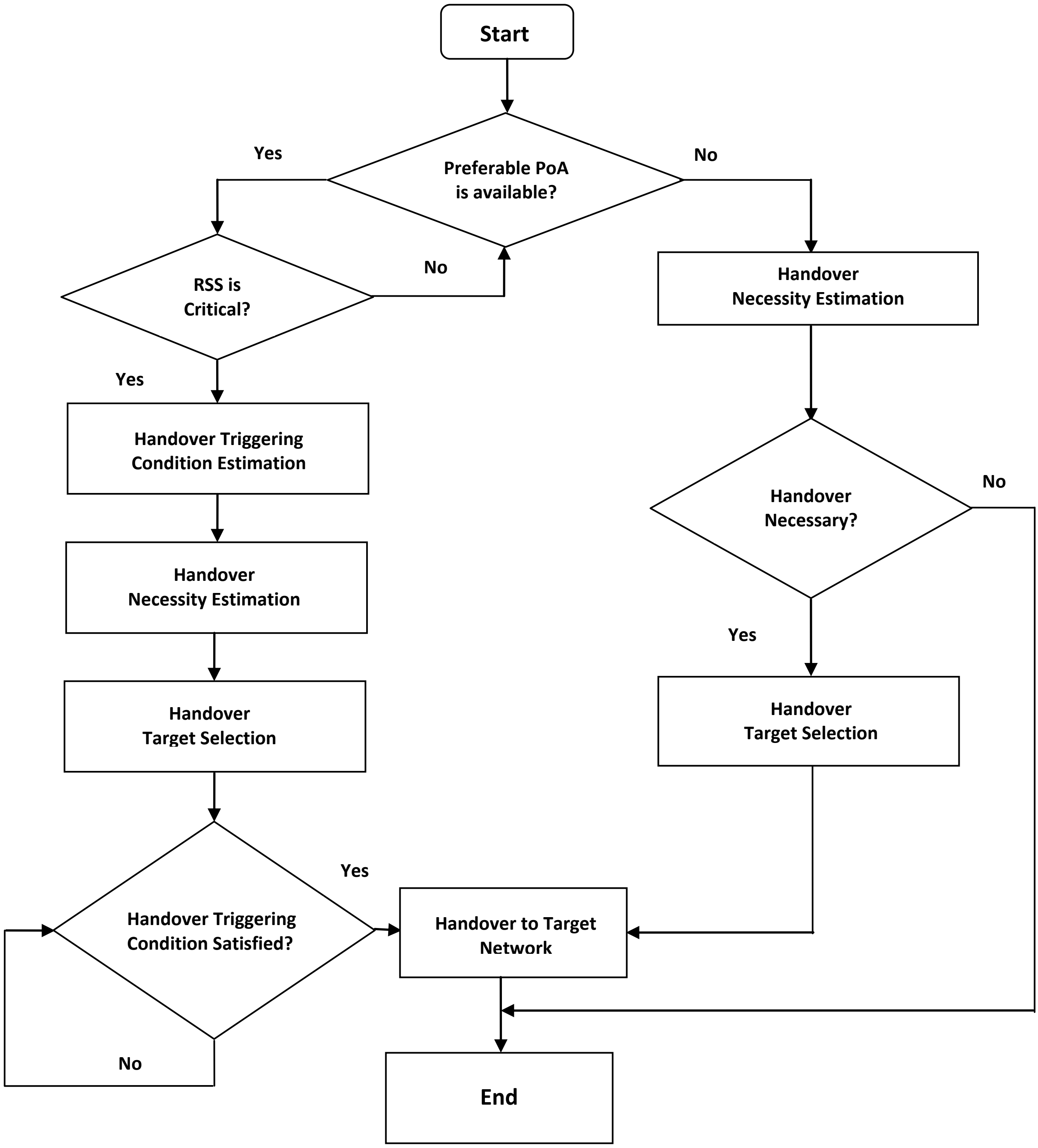


**Figure 2:** Vertical Handover Decision Process

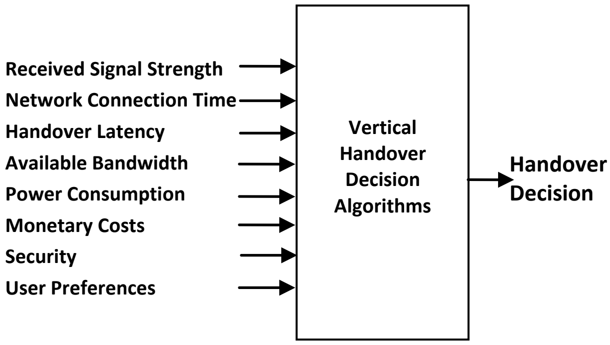


**Figure 3:** Parameters for VHD Decision Process

## 3. CLASSIFICATION OF VHD ALGORITHMS

Literature reveals that a number of studies have previously been published, wherein, design and performance issues of the VHD polices were presented along with analysis / comparison of several VHD algorithms. However, focus of these studies were quite narrow with some covering RSS and cost function based algorithms [12], and some comparing the performance of VHD algorithms on the system resource utilization and QoS perceived by users [13]. In this paper, a representative set of VHD algorithms have been categorized in four groups based on the main handover decision criterion used. Their operational fundamentals along with advantages / disadvantages have also been presented in Table II.

- *RSS Based Algorithms* – compares RSS of the current PoA with that of the candidates PoA, so as to make a handover decision. Because of simplicity of required hardware for RSS measurement – significant number of studies have been conducted in this area. Zahran et al. [14] proposed a handover algorithm between the 3G cellular networks and WLANs by combining the RSS measurement either with an estimated life-time metric or available bandwidth of WLAN candidate. Similarly, Mohanty and Akyildiz [15] proposed the WLAN to 3G handover decision mechanism based on the comparison of current RSS and dynamic RSS threshold, when MT is connected to a WLAN access point.
- *Bandwidth Based Algorithms* – regards the available bandwidth as one of the main criterion in this group. Lee et al. [16] designed a QoS based VHD algorithm which considers wireless network transport capacity (i.e. residual bandwidth) and user service requirements for integrating the WLAN with Wireless Wide Area Network (WWAN). Similarly, Yang et al. [17] devised a bandwidth based VHD scheme which uses Signal to Interference & Noise Ratio (SINR) as handoff criterion among the different access networks, i.e. WLANs and Wideband Code Division Multiple Access (WCDMA).
- *Cost Function Based Algorithms* – combine metrics such as the security, available bandwidth, monetary costs, power consumption, etc. in a cost function; and handover decision is made by comparing the results of this function with that of candidates network. Zhu & McNair [18] proposed a complex, adaptive and intelligent algorithm that relies on cost function to calculate the total cost [i.e. sum of cost of each QoS parameters including bandwidth, battery power and delay] of the possible target networks. However, the authors didn't illustrated normalization of QoS factors and how weights for QoS factors are assigned. This was later addressed by Hasswa et al. [19].
- *Combination Algorithms* – attempts to use richer set of inputs than the other schemes for making handover decisions. This makes it quite difficult or impossible for researchers to develop analytical formulations of the handover decision processes; and machine learning techniques [*fuzzy logic / artificial neural networks*] are thus widely employed. Nasser et al. [20] developed an intelligent VHD scheme based on the artificial neural networks that has capability to select best available wireless network by taking the advantage of the user preferences, device capabilities and wireless network features. Xia et al [21] employed fuzzy logic technique for performing the vertical handover between WLANs and Universal Mobile Telecommunication Systems (UMTS) based on the three inputs, i.e. current RSS, predicted RSS and bandwidth.

## 4. CONCLUDING REMARKS AND FUTURE DIRECTIONS

Research into VHD algortithms for hetrogeneous wireless networks still remains a challenging area. The survery presented herein depicts that presently proposed VHD algorithms either lacks a comprehensive consideration of various network parameters or studies' reporting these problems lack sufficient detail for implementation. The challenge is to thus devise an algorithm that encompasses wide ranging network conditions and user preferences. One possible solution is to improve the computional power of handsets, implement VHD algorithms in handsets and adopt adaptive schemes that opt for algorithms intelligently based on a fixed set of parameters.

**Table 3:** A Comparative Summary of the Eight (8) VHD Algorithms

| Group / Heuistics | | Applicable Networking Technologies | Advantages | Disadvantages |
|---|---|---|---|---|
| **RSS Based** | **Zahran, Liang & Saleh (2006)** | Between 3Gs and WLANs | Adaptation to application requirements and user mobility<br><br>Number of handovers reduced by 85% as compared with tradional hysteresis VHD | High packet delay<br><br>Extra lookup table<br><br>No considerations for the handover failure probability |
| | **Mohanty & Akyildiz (2006)** | | Reduction of the false handover initiation and handover failure probabilities [can always be kept under the desired value (2%) as the velocity increases] | No considerations for the packet delay and throughput |
| **Bandwidth Based** | **Lee et al. (2005)** | Between WWANs and WLANs | High overall throughput<br><br>Low handover latency for the real-time transmission | Difficulty in acquiring available bandwidth information<br><br>No considerations for number of handovers and handover failure probability |
| | **Yang et al. (2007)** | Between WCDMA and WLANs | Higher overall throughput (upto 40%) than RSS based handover algorithms<br><br>Balance of network load between WCDMA and WLANs | Excessive handovers due to the variation of SINR<br><br>No considerations for the packet delay and handover failure probability |
| **Cost Function Based** | **Zhu & McNair (2006)** | Between any two Heterogeneous Wireless Networks | High overall throughput<br><br>Increased user satisfaction<br><br>Low blocking probability | Missing detailed information pertinent to the normalization of QoS factors and how weights for QoS factors are assigned<br><br>No considerations for the packet delay, number of handovers and handover failure probability |
| | **Hasswa, Nasser & Hassanein (2006)** | | High overall throughput (increases upto 57.9%)<br><br>Increased user satisfaction | Difficulty in estimating the security and interference levels<br><br>No considerations for the packet delay, number of handovers and handover failure probability. |
| **Combination Based** | **Nasser, Guizani & Al - Masri (2007)** | | High success rate for finding best candidate network | High packet delay<br><br>No considerations for number of handovers, handover failure probability and throughput.<br><br>Increased system complexity |
| | **Xia, Jiang & He (2007)** | Between WLANs and Cellular Networks | Reduced number of unnecesary handovers by avoiding the ping-pong effect | No considerations for the packet delay, handover failure probability and throughput.<br><br>Fixed number of weights are not practical due to the varying nature of the network conditions and user requirements. |

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