Vertical Handover in beyond Third Generation (B3G) Wireless Networks*

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Abstract. Currently, there are several wireless networks deployed around the world. Examples include cellular networks, metropolitan area networks, wireless local area networks, and personal area networks. The combination of all these networks is usually called the beyond 3G (B3G) wireless networks. New state-of-the-art mobile terminals will allow users to freely move and to switch connections among different access networks. This process named vertical handover imposes important technical challenges for the emerging B3G wireless networks. In this paper, first the vertical handover is classified and its difference with the traditional horizontal handover is explained. Our contributions to this research field with focus on the vertical handover decision process are mentioned together with a suitable survey of related work in this area.

Key words: vertical handover, vertical handoff, handover decision algorithm, B3G wireless networks, heterogeneous wireless networks

1 Introduction

Currently, there are various wireless networks deployed around the world. Examples include second and third generation (3G) of cellular networks (e.g., GSM/GPRS, UMTS, CDMA2000), metropolitan area networks (e.g., IEEE 802.16, WiBro), wireless local area networks WLANs (e.g., IEEE 802.11a/b/g, HiperLAN), and personal area networks (e.g., Bluetooth). All these wireless networks are heterogeneous in sense of the different radio access technologies and communication protocols that they use and the different administrative domains that they belong to [1]. From this fact, it follows that no access technology or service

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provider can offer ubiquitous coverage expected by users requiring connectivity anytime and anywhere.

The actual trend is to integrate complementary wireless technologies with overlapping coverage, to provide the expected ubiquitous coverage and to achieve the *Always Best Connected* (ABC) concept [2]. The ABC concept allows the user to use the best available access network and device at any point in time. In order to accomplish the integration and inter-working between B3G wireless networks and the ABC concept, many challenging research problems have to be solved, taking into account the fact that all these new wireless technologies were designed without considering any interworking among them.

In B3G networks, the emerging state-of-the-art mobile devices will be equipped with multiple network interfaces to access different networks. These new mobile devices will provide the user with great flexibility for network access and connectivity but also generate the challenging problem of mobility support among different networks. Users will expect to continue their connections without any disruption when they move from one network to another. This important process in wireless networks is referred to as *handoff* or *handover* [3].

Traditionally, the handover process has been considered and studied among wireless networks using the same access technology (e.g., among cells of a cellular network). This kind of handover process is defined as *horizontal handover* (HHO). Now, with the emerging mix of overlapped B3G wireless networks deployed, the handover is a more complicated process and previous handover management techniques cannot be used [4]. The new handover process among networks using different technologies is defined as *vertical handover* (VHO) [6]. To deal with this new problem, novel handover techniques are required [5].

The objective of this paper is to introduce the VHO in B3G wireless networks with focus on the VHO decision. In Section 2, the concept and classifications of VHOs are presented. In Section 3, the VHO decision and related work are presented and our contributions in this research area are briefly discussed. Section 5 summarizes and concludes this paper.

2 Vertical Handover

In the context of cellular networks a handover is defined as the mechanism by which an ongoing connection is transferred from one base station (BS) to another [3]. The BSs are the infrastructure (i.e., antennas, towers) that is deployed by the cellular operator to provide service in a geographic area. In this simple case, if we consider that both BSs use the same access technology, as in current cellular systems, we can say that homogeneous wireless networks perform HHO [6]. Such handover mechanisms mainly use signal strength measurements from the surrounding BSs to trigger and to perform the handover. The HHO algorithm decides in which BS the connection should be transferred to. It is usually the BS which provides the highest signal level to the mobile device.

On the other hand, if we consider heterogeneous wireless networks such as the B3G networks, with BSs from cellular networks using one access technology

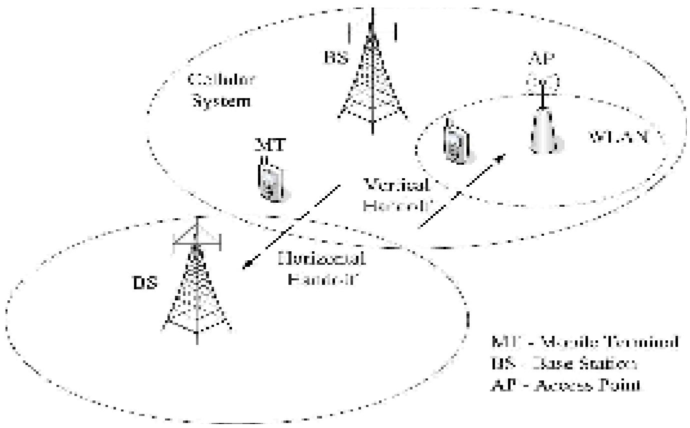

Fig. 1. Horizontal and Vertical Handovers in beyond 3G (B3G) wireless networks.

and access points (APs) from WLANs using a different one, we can say that a VHO is the mechanism by which an ongoing connection is transferred from one BS to an AP and vice versa [6]. The different handovers can be seen in Fig. 1. It is worth to mention that the mechanisms to support VHOs required in a B3G network environment have to be designed by considering the trade-off among several technical objectives such as low latency, power saving, and required bandwidth. Furthermore, the handover decision in this case becomes a more complex process than in homogeneous wireless networks because of the additional parameters, besides the signal strength, that have to be considered. A further discussion about this process will be presented in following sections.

2.1 Classification of Vertical Handovers

The handovers can be classified in many different ways (e.g., horizontal and vertical as in Fig. 2a. For VHO, there are two additional and useful classifications to understand why VHO mechanisms are different from traditional HHO mechanisms signal strength-based.

The first classification is: *upward* and *downward* [6]. An upward VHO occurs from a network with small coverage and high data rate to a network with wider coverage and lower date rate. On the other hand, a downward VHO occurs in the opposite direction. As an example for this classification let's consider the case of two of the most important current wireless technologies: 3G cellular networks and WLANs. The WLAN system can be considered as the small coverage network with high data rate while the 3G cellular system is the one with wider coverage and lower data rate. The trend in the literature has been to perform downward VHOs whenever possible.

The second classification is: *imperative* and *alternative* [7]. An imperative VHO occurs due to low signal from the BS or AP. In other words, it can be considered as an HHO. The execution of an imperative VHO has to be fast in order to keep on-going connections. On the other hand, a VHO initiated to

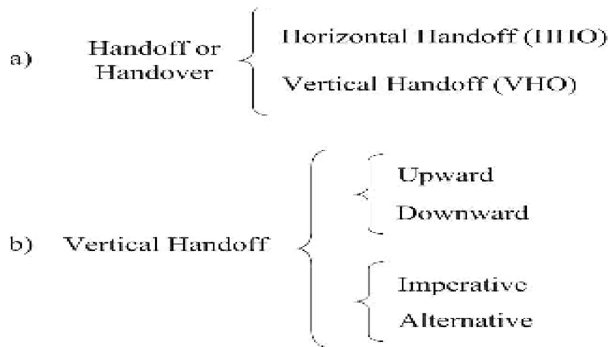

Fig. 2. Useful classification for handovers.

provide the user with better performance (e.g., more bandwidth or lower access cost) is considered to be an alternative VHO. This VHO can occur when a user connected to a 3G cellular network goes inside the coverage of a WLAN, even if the signal of the connection to the 3G cellular network does not lose any signal strength, the user may consider the connection to the WLAN a *better* option.

A summary of the classifications is shown in Fig. 2b. In order to find the *best network*, the handover decision mechanism requires more information and parameters to decide which network to perform a handover to. These information and parameters are commonly referred to as *handover metrics*. They are qualities and quantities that are measured to give an indication of whether or not a handover is needed and they may also help to decide the target network. While the main metric in HHO is the received signal strength from the BSs, in VHO there are more parameters that need to be considered. Examples include: the different data rates offered, coverage areas, access costs, security capabilities, and communication services.

3 Vertical Handover Decision

In general, the VHO process can be divided into three main steps [4],[8], namely *system discovery*, *handover decision*, and *handover execution*. During the system discovery step, the mobile terminals equipped with multiple interfaces have to determine which networks can be used and the services available in each network. These wireless networks may also advertise the supported data rates for different services. During the handover decision step, the mobile device determines which network it should connect to. The decision may depend on various parameters or handover metrics including the available bandwidth, delay, jitter, access cost, transmit power, current battery status of the mobile device, and even the user's preferences. Finally, during the handover execution step, the connections need to be re-routed from the existing network to the new network in a seamless manner. This step also includes the authentication and authorization, and the transfer of user's context information.

3.1 Related Work

Regarding the second step, various VHO decision algorithms have been proposed recently. The decision algorithms use handover metrics to decide which the best network to use is. It is usually referred to as the *target network*. For example, in [9], the VHO decision mechanism is formulated as an optimization problem. Each candidate network is associated with a cost function. The decision is to select the network which has the lowest cost value. The cost function depends on a number of criteria, including bandwidth, delay, and power requirement. Appropriate weights are assigned to each criterion to account for its importance.

In [10], the VHO decision is formulated as a fuzzy MADM (Multiple Attribute Decision Making) problem. Fuzzy logic is used to represent the imprecise information of some attributes and user preferences. Two classical MADM methods are proposed SAW (Simple Additive Weighting) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution).

In [11], the network selected is based on Analytic Hierarchy Process (AHP) and Grey Relational Analysis (GRA). AHP decomposes the network selection problem into several sub-problems and assigns a weight value for each subproblem. GRA is then used to rank the candidate networks and to select the one with the highest ranking.

In [12] a context based handover decision procedure is proposed for WLANs and CDMA systems. Information parameters such as call dropping probability, call blocking probability, grade of service, the number of handover attempts and velocity are used for the handover decision. A velocity threshold is calculated to optimize the performance of the wireless system.

In [13], the authors propose an Autonomic Handover Manager (AHM) based on the autonomic computing concept to decide the best network interface to handover in B3G wireless networks. The AHM decides the best policy for the specific service or application without the intervention of the user and using the context information from the mobile terminal, the network and the user. The context information is classified into static, static in a cell and dynamic depending on its evolution over time.

Recently, in [14], the use of ELECTRE, a type of MADM algorithm, in proposed for network selection in heterogeneous wireless networks. ELECTRE performs pair-wise comparisons amongst the alternatives, to select the best network. The original ELECTRE algorithm is modified to able to provide a complete ranking of networks even in scenarios where the utility is nonmonotonic.

3.2 Contributions

As mentioned in the previous section, there are several VHO decision algorithms recently proposed, but to the best of our knowledge there is no performance comparison among them. Based on this fact, in [15], we compare the performance of four decision algorithms proposed for VHO. SAW and TOPSIS from [10], GRA from [11], and the Multiplicative Exponent Weighting (MEW) are compared. A B3G scenario where four wireless networks are available for VHO is simulated by using stochastic models and several kinds of traffic (i.e., conversational, streaming, interactive, and background). Handover metrics such as available bandwidth, packet delay, jitter, and bit error rate are considered. The results show that although the performance of the four algorithms is very close, in some situations, GRA is able to provide a slightly better performance than SAW, TOPSIS and MEW. Finally, the simulation results show that MEW, SAW and TOPSIS select the same network for VHO more than 90% of the time and the four algorithms select the same network more than 70% of the time.

A mobile device in a B3G wireless network environment has to make a decision about the target network either periodically or every time that a new network is discovered. This kind of sequential decision problems can be modeled as a Markov decision process (MDP). In [16], we formulate the VHO decision problem as an MDP. Suitable and flexible reward and cost functions are introduced to capture the tradeoff among the network resources utilized by the connection (i.e., QoS in terms of available bandwidth and delay) and the signaling and processing load incurred in the network when the VHO is executed. The objective of the MDP formulation is to maximize the expected total reward per connection. Such optimization problem is formulated as:

$$v(\mathbf{s}) = \max_{a \in A} \left\{ r(\mathbf{s}, a) + \sum_{\mathbf{s}' \in S} \lambda \, P[\mathbf{s}' \mid \mathbf{s}, a] \, v(\mathbf{s}') \right\}, \tag{1}$$

where $v(\mathbf{s})$ is the expected reward, A is the set containing the possible actions (i.e., which network to use), $r(\mathbf{s}, a)$ is the reward function, and $P[\mathbf{s}' \mid \mathbf{s}, a]$ the state transitions probabilities of the B3G system.

The MDP optimization problem is solved using the value iteration algorithm [17], and a stationary optimal policy is obtained. The optimal MDP vertical handover policy indicates which is the optimal network to use based on the state of the B3G system. The performance of the MDP handover algorithm is compared to other VHO decision algorithms such as SAW and GRA and also to a couple of heuristic policies. The results show good improvement in a wide range of conditions.

Fig. 3 shows the expected total reward per connection for all the decision algorithms when the switching cost of executing a VHO is increased. The switching cost represents the signaling cost (i.e., procedures, re-routing of packets, etc.) generated in the networks when the VHO is executed. We can see that the proposed MDP algorithm achieves the largest expected reward per connection.

Fig. 4 shows an example of the MDP handover policy for a B3G scenario of 2 networks. In the figure, the mobile device is currently connected to network 2. The presence of cube represents the action switch the connection to network 1 (i.e., execute a VHO to network 1), while the absence of cube represents the action reaming using the network 2.

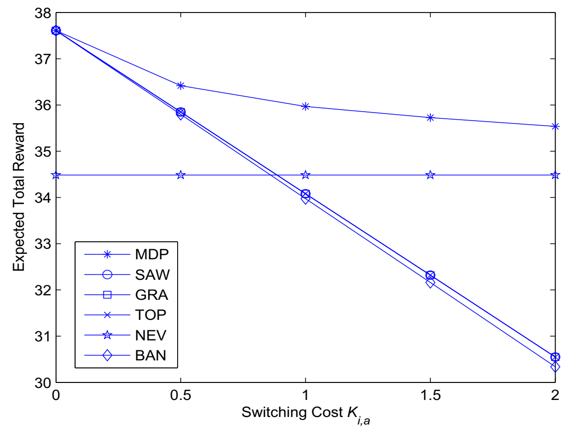

Fig. 3. Effect of the switching cost in the expected reward per connection [16].

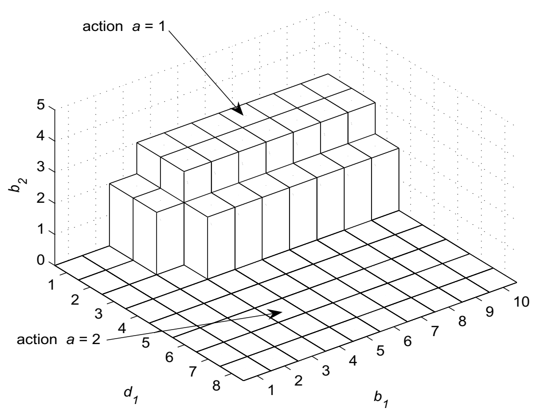

Fig. 4. Example of the optimal MDP VHO policy.

4 Summary and Open Issues

This paper presents the vertical handover as an important element in the emerging B3G wireless networks. The vertical handover is classified, its difference with the traditional horizontal handoff is explained and its steps are presented with focus on the vertical handoff decision. Suitable related work is summarized and our current contributions to this research field are mentioned. Specifically, a vertical handover decision algorithm based on MDP is described. There are several open issues that need to be further investigated in the integration of B3G wireless networks. Examples include the load balancing and traffic management among networks, Quality of Service (QoS) support during vertical handover, connection admission control, resource sharing and resource allocation, security and authentication, billing and operator agreements, and implementation details.

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