A Smart Decision Model for Vertical Handoff

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***Abstract* – As mobile computing increases in prevalence and popularity, it is becoming increasingly important to have a vertical handoff solution, which can perform a vertical handoff seamlessly and smartly. In this paper, we propose a Smart Decision Model to decide the "best" network interface and "best" time moment to handoff. A score function is utilized in the model to make the smart decision based on various factors, such as the properties of available network interfaces, the system information, and the user preferences. A USHA based testbed is created to evaluate this model in various scenarios, and the results show that our model is feasible and helpful in mobile computing scenarios. Additionally, this model is simple and also applicable to other vertical handoff approaches.**

***Key-Words* – seamless handoff, vertical handoff, smart decision, policy-based handoff, mobile computing**

1 Introduction

As mobile computing increases in prevalence and popularity, 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 interface to use any given moment. It is apparent to us that the decision should be based on various considerations such as the capacity of each network link, ISP charge of each network connection, power consumption of each network interface, and battery status of the mobile device.

A similar policy-based handoff scheme has been proposed in [18], where the authors designed a cost function to decide the "best" moment and interface for vertical handoff. However, the cost function presented in this paper is very preliminary and not able to handle more sophisticated configurations. The logarithmic function used in the cost function will also have difficulty in representing the cost value while the value of the constraint factor is zero (e.g. the connection is free of charge). Another scheme proposed in [1] models the handoff with HTTP traffic, but it may have problems with other types of traffic, such as video and audio streaming, where the bandwidth demand is much higher than HTTP traffic.

In this study, we propose a *Smart Decision Model* to smartly perform vertical handoff among available network interfaces. Using a well-defined score function, the proposed model can properly handoff to the "best" network interface at the "best" moment according to the properties of available network interfaces, system configurations/information, and user preferences. A *Smart Decision Model* implementation is employed on the top of the Universal Seamless Handoff Architecture (USHA), which is a simple and practical seamless handoff solution [2], and a set of experiments are performed to evaluate the feasibilities of the model. The results show that the proposed smart decision model can adequately perform vertical handoff to the "best" interface at the "best" moment.

The rest of the paper is organized as follows: Section 2 describes the handoff overview and a simple seamless handoff approach, USHA. Section 3 presents our proposed Smart Decision Model. Section 4 demonstrates the model using a detailed example. Finally, section 5 concludes the work.

2 Background

In this section, we present the background of this study. Section 2.1 clarifies the difference of vertical and horizontal handoff, and defines the seamless handoff. In section 2.2, we describe a simple and practical handoff approach: USHA, which will be used in the following discussions and testbed experiments.

2.1 Handoff

Handoff occurs when the user switches between different network access points. Handoff techniques have been well studied and deployed in the domain of cellular system and are gaining a great deal of momentum in the wireless computer networks, as IP-based wireless networking increases in popularity.

Differing in the number of network interfaces involved during the process, handoff can be characterized into either *vertical* or *horizontal* [16], as depicted in Figure 1. A vertical handoff involves two different network interfaces, which usually represent different technologies. For example, when a mobile device moves out of an 802.11b network and into a 1xRTT network, the handoff event would be considered as vertical. A horizontal handoff occurs between two network access points that use the same technology and interface. For example, when a mobile device moves between 802.11b network domains, the handoff event would be considered as horizontal since the connection is disrupted solely by the change of 802.11b domain but not of the wireless technology.

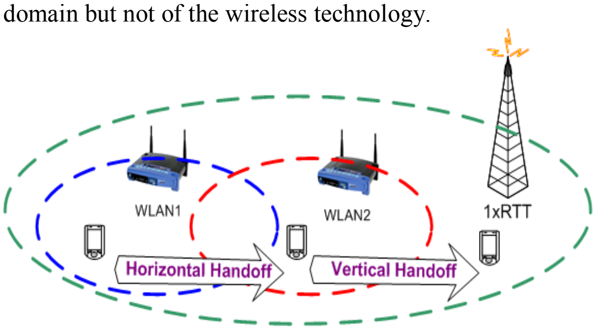

Figure 1: Horizontal and Vertical Handoff

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. Achieving low latency and minimal packet loss during a handoff are the two critical design goals of our handoff architecture. To achieve low latency path switching should be completed almost instantaneously and service interruptions should be minimized. In case of an actual connection failure, the architecture should attempt to re-connect as soon as the service becomes available; packet losses during the switching should also be minimized.

Various seamless handoff techniques [4][7][8][10] have been proposed. These proposals can be classified into two categories: network layer approaches and upper layer approaches. Network layer approaches are typically based on IPv6 [3] or Mobile IPv4 [13] standards, requiring the deployment of several agents on the Internet for relaying and/or redirecting the data to the moving host (MH). Most upper layer approaches implement a session layer above the transport layer to make connection changes at underlying layers transparent to the application layer [6] [11][14][15]. Other upper layer approaches suggest new transport layer protocols such as SCTP [17] and TCP-MH [12] to provide the necessary handoff support.

Previous 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. The cost imposed by these solutions hinders their chances of deployment. For the upper layer solutions, a new session layer or transport protocol requires an update to all existing applications and servers not supporting it, the potential cost is also discouraging. Consequently, even though many 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. With the proliferation of mobile applications and mobile users, a "simple" and "practical" seamless handoff solution with minimal changes to the current Internet infrastructure remains necessary.

In the next subsection, we present a simple and practical handoff solution, USHA, which is able to provide both vertical and horizontal handoff seamlessly.

2.2 Universal Seamless Handoff Architecture

A Universal Seamless Handoff Architecture (USHA) was proposed in [2] to deal with both horizontal and vertical handoff scenarios with minimal changes in infrastructure (i.e., USHA only requires deployment of handoff servers 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 [5], 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.

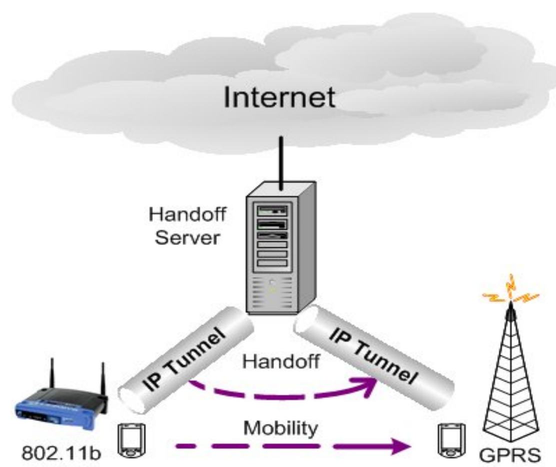

Figure 2: Universal Seamless Handoff Architecture

In Figure 2, a handoff server (HS) and several mobile hosts (MHs) are shown. USHA is implemented using IP tunneling techniques (IP encapsulation), with the handoff server functioning as one end of the tunnel and the mobile host as the other. An IP tunnel is maintained between every MH and the HS such that all application layer communications are "bound" to the tunnel interface instead of any actual physical interfaces. All data packets communicated through this IP tunnel are encapsulated and transmitted using the connectionless UDP protocol.

The IP tunnel above utilizes two pairs of virtual/fixed IP addresses, one on HS and one on MH. The fixed IP addresses are necessary for an MH to establish a physical connection to the HS. When the handoff event occurs and the physical connection from MH to HS changes, the MH is responsible for automatically switching the underlying physical connection of the virtual tunnel to the new interface, as well as notifying the HS of its change in physical connection. Upon handoff notification, the HS immediately updates its IP tunnel settings so that any subsequent data packets will be delivered to MH's new physical link. Since all data packets are encapsulated and transmitted using UDP, there is no need to reset the tunnel after the handoff. Therefore, end-to-end application sessions (e.g. TCP) that are bound to the IP tunnel are kept intact. This provides handoff transparency to upper layer applications.

On the other hand, though USHA provides a simple and practical seamless handoff solution, it still has difficulty in performing handoff smartly, i.e. the handoff cannot be triggered automatically so far. It turns out that a manual handoff solution is still far from becoming practical, since an appreciable solution should keep mobility transparent to the mobile users, i.e. the seamless handoff solution should be "smart" enough so that it is able to perform a handoff properly at the proper moment.

A *Smart Decision Model* is proposed in this study. In the proposed model, a handoff decision is made based on the network properties, system information, and user preferences. Additionally, it is able to perform a handoff automatically to the "most appropriate" network interface at the "most appropriate" moment. The proposed model is designed for USHA and is also applicable to other handoff approaches. The details of the proposed Smart Decision Model are presented in section 3, and a real testbed implementation and experiment results will be presented in section 4.

3 Smart Decision Model

In this section, we present the proposed *Smart Decision Model* to support flexible configuration in executing vertical handoffs. Figure 3 depicts the proposed Smart Decision Model. In this figure, a Handoff Control Center (HCC) provides the connection between the network interfaces and the upper layer applications. HCC is composed of four components: Device Monitor (DM), System Monitor (SM), Smart Decision (SD), and Handoff Executor (HE). DM is responsible for monitoring and reporting the status of each network interface (i.e. the signal strength, link capacity and power consumption of each interface). SM monitors and reports system information (e.g. current remaining battery). SD integrates user preferences (obtained from user set default values) and all other available information provided by DM, SM to achieve a "Smart Decision", to identify the "best" network interface to use at that moment. HE then performs the device handoff if the current network interface is different from the "best" network interface.

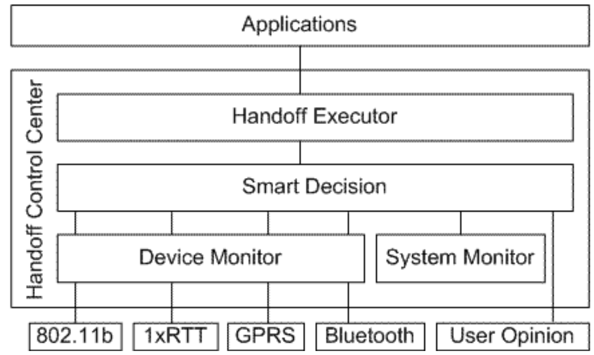

Figure 3: Smart Decision Model

A Handoff Control Center (HCC) in accordance to above has been implemented on our vertical handoff testbed to perform automatic handoffs to the "best" network interface. In our design, there are two phases in SD: the *priority* phase and the *normal* phase. The SD algorithm is described in Figure 4.

Smart Decision Process

Priority Phase:

1. *Add all available interfaces into candidate list.*
2. *Remove user specified devices from the candidate list.*
3. *If candidate list is empty, add back removed devices from step 1*
4. *Continue with Normal Phase.*

Normal Phase:

1. *Collect information on every wireless interface in the candidate list from the DM component.*
2. *Collect current system status from SM component.*
3. *Use the score function to obtain the score of every wireless interface in the candidate list.*
4. *Handoff all current transmissions to the interface with the highest score if different from current device.*

Figure 4: Algorithm for making Smart Decisions on HCC

Priority and normal phases are necessary in SD to accommodate user-specific preferences regarding the usage of network interfaces. For instance a user may decide not use a device when the device may cause undesirable interferences to other devices (e.g. 802.11b and 2.4GHz cordless phones). With priority and normal phases in place, the SD module provides flexibility in controlling the desired network interface to the user. Additionally, SD deploys a *score function* to calculate a score for every wireless interface; the handoff target device is the network interface with the highest score. More specifically, suppose there are k factors to consider in calculating the score, the final score of interface i will be a sum of k weighted functions. The *score function* used is the following:

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

In the equation, w_j stands for the weight of factor k, and $f_{j,i}$ represents the normalized score of interface i of factor j. The "best" target connection interface at any given moment is then derived as the one which achieves the highest score among all candidate interfaces. We further break down the score function to three components where each accounts for usage expense (E), link capacity (C), and power consumption (P), respectively. Therefore Eq. 1 becomes:

$$S_i = w_e f_{e,i} + w_c f_{c,i} + w_p f_{p,i} \qquad (2)$$

Additionally, there is a corresponding function for each term $f_{e,i}$, $f_{c,i}$, and $f_{p,i}$, and the ranges of the functions are bounded from 0 to 1. The functions are illustrated below:

$$f_{e,i} = \frac{1}{e^{\alpha_i}} \quad f_{c,i} = \frac{e^{\beta_i}}{e^{M}} \quad f_{p,i} = \frac{1}{e^{\gamma_i}} \qquad (3)$$

$$\text{where } \alpha_i \geq 0, M \geq \beta_i \geq 0, \text{and } \gamma_i \geq 0$$

The coefficients α_i, β_i, γ_i can be obtained via a lookup table or a well-tuned function. In Eq. 3, we used the inversed exponential equation for $f_{e,i}$ and $f_{p,i}$ to bound the result to between zero and one (i.e. these functions are normalized), and properly model users preferences. For $f_{c,i}$, a new term M is introduced as the denominator to normalize the function, where M is the maximum bandwidth requirement demanded by the user. Without specified by the user, the default value of 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).

4 Testbed Experiments

A *Smart Decision Model* implementation is employed on the top of USHA vertical handoff testbed, and a set of experiments has been performed to evaluate this model. Our Smart Decision Model implementation worked well in all the testing scenarios. To clearly demonstrate how this model works, we show a detailed example in the followings.

An example of how these coefficients in *Smart Decision Model* work with user defined functions is illustrated in Figure 5, where x_i is the usage cost (ISP charge), y_i is the measured link capacity, and z_i is the power consumption of the i-th wireless interface. In a sense, these functions are simply transformation from a specific domain (e.g. ¢ /min, kbps, and hours) to a universal unit domain, and the return values are normalized as a positive real number between 0 and 1. On top of that, the user can also decide what she values the most by giving weight w_j to j-th function.

$\alpha_i = x_i / 20$	; x_i : ¢ /min
$\beta_i = Min(y_i, M)/M$	; M = 2Mbps
$\gamma_i = 2 / z_i$	; z_i : hours

Figure 5: An coefficient function example

The following illustrates an example of how Smart Decision is achieved. Suppose a mobile user who is currently using the 1xRTT device enters a café. The HCC immediately discovers an 802.11b access point inside the café and does the following comparisons: The 1xRTT cost is less than 1 ¢ /min because the user has already subscribed to the service using monthly unlimited plan ($80 / month), while 802.11b inside the café costs 10 ¢ /min. The link capacity information is gathered from CapProbe [9], a newly invented capacity estimation tool, which reports that 1xRTT has a capacity of 100Kbps and the 802.11b wireless LAN has a capacity around 5Mbps. With the current battery status, the user can either continue his 1xRTT connection for 4 hours or 2 hours with 802.11b connection. At this time, the mobile user decides that he will stay in the café for a while, so he gives more weight to power consumption (w_p=0.4), and equal weight to usage cost and bandwidth requirement (w_e = 0.3, w_c = 0.3). The HCC then computes the score according to Eq. 2 and Eq. 3 using coefficient functions illustrated in Figure 5. Figure 6 displays the score results of both 1xRTT and 802.11b interfaces, where $S_{1xRTT} = 0.83$ and $S_{802.11b} = 0.44$. Since $S_{1xRTT} > S_{802.11b}$, the HCC therefore decides to continue using 1xRTT interface instead of switching to the faster 802.11b interface.

$$\begin{aligned} S_{1xRTT} &= 0.3 \times \frac{1}{e^{\alpha}} + 0.3 \times \frac{1}{e^{\beta}} + 0.4 \times \frac{1}{e^{\gamma}} \\ &= 0.3 \times \frac{1}{e^{0}} + 0.3 \times \frac{1}{e^{100kbps/2Mbps}} + 0.4 \times \frac{1}{e^{2/4}} \\ &\approx 0.83 \\ S_{802.11b} &= 0.3 \times \frac{1}{e^{\alpha}} + 0.3 \times \frac{1}{e^{\beta}} + 0.4 \times \frac{1}{e^{\gamma}} \\ &= 0.3 \times \frac{1}{e^{10/20}} + 0.3 \times \frac{1}{e^{Min(2,5)Mbps/2Mbps}} + 0.4 \times \frac{1}{e^{2/2}} \\ &\approx 0.44 \end{aligned}$$

Figure 6: An HCC calculation example for both 1xRTT and 802.11b interfaces

Note that, though the example shown in this section uses the coefficient functions defined in Figure 5, these coefficients are changeable upon users' needs and preferences. These coefficients can be obtained via a lookup table or a well-tuned function; however, they need to be normalized so that the score function (Eq. 1) can reasonably decide the score for each network interface from different factors.

5 Conclusion

In this paper, we present a Smart Decision Model to "smartly" perform handoff to the "best" network interface at the "best" moment. The proposed model is able to make the "smart" decision based on the properties of available network interfaces (e.g. link capacity, power consumption, and link cost), system information (e.g. remaining battery), and user preferences. Using USHA testbed experiments, we presented a detailed example to show how this model works with given a set of coefficient functions. The Smart Decision Model is simple and applicable not only for USHA, but also for other vertical handoff approaches.

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