Experiences with SeaMo: A Vertical Handoff Implementation for Heterogeneous Wireless Networks

Seema K, Gopi Krishna S Garge, Anand S V R, and Malati Hegde*

E C E Department, Indian Institute of Science, Bangalore 560 012

E-Mails: {seema, anand, malati}@eis.iisc.ernet.in;  gopi@serc.iisc.ernet.in
Tel.: +91-80-23600855; Fax: +91-80-23600991
http://dx.doi.org/10.7125/APAN.32.10      ISSN 2227-3026

Abstract: SeaMo, a vertical handoff (VHO) implementation based on our earlier paper [1] is tested with various mobility scenarios on a mobile IP testbed using MIPv6 and HIP protocols for mobility management. SeaMo considers various parameters like RSSI, link quality metric, end-to-end available bandwidth, battery power, network usage costs etc., in making the VHO decision. We present our experiences using SeaMo in mobility scenarios involving 3G and WLAN. We present a set of results which demonstrate the performance of SeaMo. We explain the need for considering a wide range of parameters from RSSI to network usage cost. We also highlight the impact of using the available battery power in decision making. In addition, we attempt to measure typical values of parameters such as network association delay, and handoff decision delay that impact the QoS.

Keywords: VHO, HIP, Handoff delay, available battery power

1. Introduction

Mobility across access networks has become a necessity for a roaming user. The mobility support is expected to be seamless and should not violate the QoS requirements of the mobile user. The critical function, therefore, is the vertical handoff across the access network segments which the user roams across. In SeaMo, handoff from one access network to another is made based on a set of decision parameters that primarily include Received Signal Strength (RSSI), end-to-end available bandwidth, battery power, cost, etc. The seamlessness of the handoff depends on the decision and its impact on the user application continuity and retention of the required QoS levels.
Refer to [1] for details of the implementation of a VHO algorithm based on fuzzy logic. SeaMo version 0.1, is tested on Linux based laptops with WLAN and 3G, on a testbed comprising network elements that support both MIPv6 [7] and HIP [8], [9] . HIP based mobility management for IPv4 is used since the 3G provider is not IPv6 enabled. This paper reports the experimental observations made on three aspects: a) Mobility scenarios and verification of handoff b) Impact of including battery power as a parameter in the decision making and c) Delays in vertical handoff when using HIP for mobility management.

The software architecture and design implementation of SeaMo is presented in section 2. The testbed description and scenarios tested are described in section 3. Handoff decision and delay measurements are discussed in section 4. Thereafter, the observations on battery utilization, impact of using battery power as a parameter in decision making is explained in section 5 followed by a conclusion in section 6.

2. SeaMo Architecture and Implementation Design

This section briefly describes the software architecture and implementation of SeaMo. The fuzzy logic based VHO decision is made based on a set of parameters monitored for each access technology.

**SeaMo: A VHO implementation for seamless mobility across HWNs**

![SeaMo - Implementation Architecture](image)

**Figure 1: SeaMo - Implementation Architecture**

Fig. 1 shows the implementation architecture of SeaMo [1]. The Pre-Handoff (PHE) module collects various decision parameter values across the access networks and passes them on to the
Handoff Decision Making & Trigger (HDT) module. 3G, WLAN and WiMAX (emulated) are the access network technologies considered. 3G parameters are obtained by querying the ModemManager daemon (on Linux) through D-Bus [12]. WLAN link related parameters are obtained using wireless-tools on Linux. QoS parameter in WLAN is obtained from NRIS [1]. WiMAX access is simulated in QualNet.

In HDT module, a fuzzy logic approach is used to make a decision. The decision attributes are the processed parameters obtained from PHE module. They are cost, user preference for the access network and battery power consumed by the access technology. (The impact of the decision by the available battery power is explained in section 5.2) Once the decision to handoff is made, the HDT module triggers the handoff by invoking Post-Handoff (PHO) module.

3. Testbed setup and Experimentation scenarios

In this section we present the test bed, its topology and components. The scenarios tested on the test bed with SeaMo are mentioned as well.

3.1 Testbed Components and Description

The testbed comprises of three network segments (refer Fig.2), each with a different network access technology - WLAN, WiMAX and 3G. Each of these network segments are interconnected via the Internet. The testbed implements two mobility management protocols MIPv6 and HIP thereby enabling us to use clients using either protocol to use the services of the network. The Correspondent Node (CN for MIPv6) and the Responder (RESP for HIP) are physically located on the ERNET-LAN at Delhi.

The mobile hosts used are laptops with Fedora Core 12 Linux distribution (Linux Kernel 2.6.31). The laptops have a built in WLAN interface. An external 3G data card used on the laptop provides multiple air interfaces.

All other hosts on the testbed also run the Fedora Core 12 Linux distribution. The Mobile host (marked Mobile User, at Bangalore) will move across networks (3G, WLAN and

**Figure 2**: IP Mobility Testbed and Components
WiMAX), on the local testbed, while streaming video from a server situated in Delhi. The mobile nodes use SeaMo for VHO across these access networks.

### 3.2. Vertical Handoff Test Scenario

We have presented test scenarios in [1]. The scenarios considered there have only one active access network of each type – 3G and WLAN. A realistic scenario would involve multiple WLAN segments and a handoff between 3G and one of these WLAN segments. This is usually the case in airports, campus, offices, etc.

![Figure 3: VHO in a university campus](image)

In this scenario the mobile user enters the IISc campus (bottom left corner of Fig 3, marked BEGIN) while associated to 3G. In the campus, there are multiple access points with the essid iiscwlan, operating in various channels. Each essid is evaluated as a separate potential network to associate to. A mobile user associated with 3G enters the campus and walks towards the SERC department. Fig. 3 shows the path followed by the user. The map also shows the WLAN coverage along the path taken to reach the destination. The algorithm hands off at Molecular Bio-Physics (MBU) department, which is represented as a red dot in the figure.
There are at least eight spots along the route where the WLAN signals are available for the VHO algorithm to decide to handoff to WLAN before the actual decision is made. We observed that there were about three access points visible in each of these spots and in one case, there were five. However, neither of them was considered feasible for handoff. The handoff occurred at MBU and the association with the iiscwlan sustained till the destination was reached. The QDVs for WLAN and 3G that were evaluated by SeaMo were examined for the entire route and found to be consistent across trials.

4. Decision and Delay Measurements

In this section, we will discuss the various delay components involved in the entire VHO process. We also present the delay values tested on the VHO algorithm implemented in [1]. The decision and the execution of the VHO are performed in 3 phases. We will specify the time consumed by each of these phases and we also discuss about handoff delay.

The delay components involved in the VHO process are explained below:
1) Time taken to make a decision to handoff or not when a new set of parameters is given to SeaMo.
2) Time taken to complete the handoff process once the handoff is triggered.

In pre-handoff phase the parameters are scanned and sent to the algorithm. The process involved in making a decision are reading and averaging the data, calculating the QEV [1] for each parameter based on the averaged data, calculating the QDV of a network from the QEVs of the parameters and the user preference for the network. The remaining battery parameter is also calculated in this process and considered for decision making. SeaMo takes 6 milliseconds to complete this process.

There are three delay components involved from the time of the trigger to complete the handoff process - a) connection time involved in connecting to a candidate network, b) the status of the connection to the new network and c) disconnection time (if the connection to the new network was successful). The connection time and the disconnection time is the time taken by NetworkManager[10] to perform these tasks. The network connection involves the following actions - i) Network access authentication ii) Obtaining IP address via DHCP, and iii) Configuring default gateway for the mobile host

The typical connection time for 3G, WLAN is given in the Table 1a. The connection time varies based on the authentication type, time of the day, distance from the access point/base station etc. Our experiments have shown that the disconnection time would be 70-80 ms.
Once the new connection is successful the mobile node disconnects from the old network. Therefore, there is one active connection at a given point in time. Ideally there should not be any packet loss. When experiments were conducted to see if there were any packet losses, we observed the results given in the Table 1b.

**Table 1. (a) Association Time. (b) Packet Loss during handoff**

<table>
<thead>
<tr>
<th>Connection Time</th>
<th>Access Network</th>
<th>SeaMo + HIP</th>
<th>SeaMo alone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min/avg/max</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/4/12 seconds</td>
<td>3G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2/2.5/5 seconds</td>
<td>WLAN (No Auth)</td>
<td>2 pkt lost</td>
<td>None</td>
</tr>
<tr>
<td>3/2.5/5 seconds</td>
<td>WLAN (with Auth)</td>
<td>3-4 pkt lost</td>
<td>1 pkt lost</td>
</tr>
</tbody>
</table>

When SeaMo was tested with HIP, an ICMP `echo_request` was initiated with the responder. We observed two ICMP packet losses while handing off from WLAN to 3G and three to four packets when handing over from 3G to WLAN. These packet losses are attributed to the location updates of the HIP between the initiator and the responder when the initiator moves to a new location (network). The handoff delay with and without HIP is shown in Table 1b.

When SeaMo was tested without HIP there were no packet losses while handing off from WLAN to 3G and there was one packet lost when handing off from 3G to WLAN. In case of WLAN, after the IP addresses and gateway are configured on the new network, the host will send an ARP request to the broadcast address asking for the identification of the gateway. Only after it receives the ARP response will the ICMP and other data packets be sent. Hence, there is a loss of the single packet. Recall that a 3G access link is a point-to-point network and does not require an ARP.

**5. VHO Decision Parameters and their Impact**

This section mentions the importance and impact of a few VHO decision parameters viz., Received Signal Strength Indicator (RSSI), Link Quality that is obtained from Linux wireless-tools and remaining battery power of the mobile host. We attempted to understand how this parameter is computed and used in implementations, typically in the Linux Kernel. The following sections detail our efforts and measurements made in this context.
5.1. Link Quality vs Received Signal Strength Indicator (RSSI) for WiFi Access Networks

The strength of a RF signal can be represented in four different units of measurements. These are: mW (milliwatts), dBm (dB-milliwatts), RSSI (Received Signal Strength Indicator), and a percentage measurement. [2] explains how these measurements are related to each other.

**RSSI:** RSSI is one of the basic parameters that is available for decision making. The literature mentions the shortcomings of RSSI as a decision parameter. The RSSI is estimated using the PLCP preamble (header) bits [3] and not the entire frame. Therefore, even if the rest of the packet other than PLCP is affected by the interference, the RSSI estimate will remain fairly stable. In the current implementations of 802.11, the transmission power level of AP is unknown to the stations [4]. Thus, a far away AP with high transmission power can have higher RSSI than an AP which is closer but with lower transmission power.

The RSSI reported by various WLAN chip set manufacturers have different RSSI_Max. The range of values provided by each vendor is different. For example, RSSI_Max of Atheros is 60 [2], Cisco provides a wide range of RSSI with RSSI_Max being 100 and Symbol has RSSI_Max of 31. From these values, the signal strength value in dBm is calculated which is generally used in decision making. Note that the conversion methods used vary across the vendors. Clearly, we require an overlapping range or normalization across the vendor implementations.

In our implementation, we represent the signal strength in units of power, dBm. This representation of the signal strength is obtained from wireless-tools package Linux. We consider the dBm value between -10 and -110, and based on this we form fuzzy sets. This causes the RSS parameter to be driver independent with the RSS range being uniform.

**Link Quality:** There is no rigid definition of the term *Link Quality*. It is intended to signify the quality of the wireless link. The value of Link Quality is dependent on its implementation in the driver and the parameters it considers for calculating the Link Quality. Upon examining the implementations of various drivers available in the Linux kernel, we find that the calculation involves multiple parameters (like RSS, missed beacons, transmit retries etc). The semantics of each of these parameters and their value ranges differ between implementations.

We use the vendor definition of Link Quality. The maximum value of the Link Quality defined by the driver is known in the user space unlike RSS where the range is not specified. Hence we calculate Link Quality as a percentage value and use it as one of the decision parameters. In SeaMo, Link Quality is given the least weight, otherwise our decision would be biased by the driver.
5.2. Impact of Battery and Power Saving

Different radio access technologies use different types of radio transceivers. Their power demand characteristics are different. The mobile device uses power to send and receive bytes through its networking interface. The battery consumption depends upon the networking technology used. The power requirement will have an impact on how the battery discharges and could therefore impact the overall duration of the availability of power in the battery. We attempt to measure the power requirements of each of the access technologies and for each such technology we compare the power requirements for similar user actions, such as file downloads, playing videos via the network, playing videos from disk and so on.

5.2.1. Impact of using Available Battery Power as a Decision Parameter

Consider two networks of different access technologies N1 and N2, where the power consumption of N1 > N2. In such a scenario we always try to connect to N2, either by remaining associated to N2 (without losing the service continuity) or by initiating a handoff to N2 as early as possible when associated to N1. By doing this we ensure that we connect to the network whose access technology consumes less power, thereby increasing the lifetime of the mobile host.

Monitoring Battery Usage: Linux offers a monitoring interface for the available battery power via the HAL daemon that uses the D-Bus interface. The battery power is monitored by querying the D-Bus interface for the battery values. When queried for remaining battery HAL daemon would return the remaining battery in seconds. The decision to handoff or not is influenced by the value of the available battery power.

5.2.2. Experiments to Estimate Battery Utilization

![Figure 4 (a) : Idle Scenario on IBM Thinkpad (b) Idle Scenario on Ideapad](image)

Figure 4 (a) : Idle Scenario on IBM Thinkpad (b) Idle Scenario on Ideapad
The experiments were conducted on two different laptops running Fedora 12 OS, Lenovo Ideapad with Intel Core 2 Duo T6400 processor and an IBM thinkpad with Intel Centrino processor. The available battery power samples were taken once in 2 seconds.

For the experiments, we measured the battery power requirement for typical actions for WLAN and 3G. The Lenovo laptop uses an Intel Pro 5100 Wireless card and the IBM laptop uses an Intel Pro 2200BG wireless card. Both used a Huawei make 3G data card (GA0301) and connected to the same upstream provider. In addition to this, both the laptops hosted the same OS version of the same distribution and had a similar start-up configuration ensuring that there were no differences in the start-up or background processes across them.

Fig. 4 shows the plot for the battery discharge in an idle scenario. In the case of each access network, the connection is made and the link is left idle. There are no packets seen on the link when the link is monitored using Wireshark[10]. Note that in this case, the WLAN uses more battery power when compared to 3G. The basic difference here is that WLAN is a shared
network where several broadcasts, multicast messages need to be received and responded to while the 3G is a point-to-point network which does not involve any such message exchange.

Fig. 5 and Fig. 6 show the battery discharge plots for downloading a file and playing a video of 10 min duration from YouTube through WLAN and through 3G. As seen in both the cases, 3G consumes more battery than WLAN.

From the experiments we observe that except for idle case, Wi-Fi consumes comparatively less battery power than 3G. This is as explained in [5] and [6].

5.2.3 Processing the available battery time parameter

When the monitored values for the current network reach a certain threshold, the VHO algorithm begins to evaluate the monitored parameters of the other networks to identify potential candidate networks. At this point the battery charge left is monitored. The QDVs of the potential network and the current network must have a minimum difference of 0.03 in order to trigger handoff. If the battery charge left is low (a remaining battery charge of 35 minutes is considered as “low” for our experiments) the minimum difference is varied, either to influence an early handoff (reduce the minimum difference, as in 3G to WLAN) or delay the handoff (increase the minimum difference, as in WLAN to 3G) depending upon the power requirements of candidate network.

![Figure 7](image1.png)

**Figure 7.** (a) Handoff point when battery parameter is considered. (b) Handoff point when battery parameter is not considered

![Figure 8](image2.png)

**Figure 8** shows the scenario considered for testing the impact of battery parameter. The mobile user starts the video stream at point A and walks till point D.

The Table 2 shows the handoff point and the time it remained in 3G network. We start the timer at

<table>
<thead>
<tr>
<th>Handoff Point</th>
<th>Without battery</th>
<th>With battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handoff occurs after</td>
<td>1 min 25 sec</td>
<td>59 sec</td>
</tr>
</tbody>
</table>

---

Table 2. Impact of using battery as a parameter
point A and note the time at which the hand off occurs. We can notice from the figure and the table, an early handoff to WLAN is initiated to conserve battery. SeaMo was also tested for WLAN to 3G, and the device handed over to 3G as expected.

Figure 8: Handoff from 3G to WLAN

6. Conclusions

SeaMo has been tested in a realistic scenario with a 3G access network and multiple WLAN segments. It has performed satisfactorily and handed off between 3G and WLAN. The delays during handoff are measured. There are two significant components – a network association delay and a mobility management delay. The association delay includes network authentication. We have observed a loss of 1 ICMP packet while handing off from 3G to WLAN and none when handing off from WLAN to 3G. When HIP mobility protocol is used, loss of 3 ICMP packets was observed.

Energy saving is an important factor in mobile devices. While the operational usage of 3G uses higher power than that for WLAN, the idle battery usage of WLAN is higher than that of 3G. Including available battery power as a VHO decision parameter enables a faster handoff to WLAN, from 3G and delays the handoff from 3G to WLAN. SeaMo version 0.1 is released on SourceForge at http://seamo.sourceforge.net/.

Acknowledgements

We acknowledge the support and funding from the Department of IT, Government of India, for the project
References


© 2011 by the authors; licensee Asia Pacific Advanced Network. This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/3.0/).