

Universal Seamless Handoff Architecture in Wireless Overlay Networks

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In view of the proliferation of mobile applications, a universal seamless handoff solution across wireless domains is becoming increasingly important. While wired connections usually provide high speed, reliable access to the Internet, wireless networking technologies enable users to access customized Internet services even when they are moving. A seamless handoff solution with both **low latency** and **low packet loss** is mandatory for mobile users who wish to receive continuous, uninterrupted Internet service while frequently switching from one network connection to another. Additionally, the handoff solution should be **network-layer-transparent** and **infrastructure-modification-free** so that existing Internet server and client applications can painlessly survive the rapid pace of wireless technology evolution.

Seamless handoff aims to provide continuous connection for an end-to-end data transmission in the face of any link outage or handoff event. Low latency and low packet loss are the two most critical design issues. Low latency requires that the switch to the new path be completed almost instantaneously; service interruption should be minimized to provide the illusion of continuous connectivity. In the event of actual connection failure, the architecture should attempt to re-connect as soon as the service becomes available, and the packet loss due to the connection switch should also be minimized.

Seamless handoff can happen either horizontally or vertically [1]. A horizontal handoff is a handoff between two network access points that use the same network technology. For example, when a mobile device moves in and out of various 802.11b [2] network domains, the handoff activities would be considered as a horizontal handoff, since the connection is disrupted solely by device mobility. A vertical handoff is a handoff between two network access points using different network connection technologies. For example, when a mobile device moves out an 802.11b network into a GPRS [3] network, the handoff would be considered a vertical handoff. The challenge in vertical handoff is to maintain the application session alive while the physical connection interface is changed.

Seamless handoff has been studied extensively [4] [5] [6] [7]. The solutions can be classified into two categories: mobile IP solutions and mobile IP-less solutions. The mobile IP solutions are typically based on IPv6 [8] or Mobile IPv4 [9] standards, requiring the deployment of different agents on the Internet for relaying and/or redirecting the data to the moving mobile host (MH). Most Mobile IP-less solutions implement a new session layer above the transport layer to make the application sessions transparent to the connection changes in the underlying layers [10] [11] [12] [13]. Other mobile IP-less solutions suggest new transport layer protocols such as SCTP [14] and TCP-MH [15] to provide the necessary handoff support. .

Previous seamless handoff solutions, regardless of mobile IP based or mobile IP-less, are often complex to implement and operate. For the mobile IP based solutions, deployment means upgrading every existing router without mobile IP capability. Needless to say, the cost imposed by these solutions hinders actually deployment. For the mobile IP-less solutions, a new session layer or a new transport protocol requires an update to all existing applications and servers not supporting those capabilities, the potential cost implies by those solutions is also not very encouraging. Consequently, even though many handoff solutions have managed to minimize both latency and packet loss, but due to the cost and the required changes to the existing Internet infrastructure, they are often deemed unacceptable to the general public. Thus, a seamless handoff solution with minimal changes to the current Internet infrastructure remains necessary.

In this paper, we propose the Universal Seamless Handoff Architecture (USHA) to deal with both horizontal and vertical handoff scenarios. USHA is a mobile IP-less solution; however, instead of introducing a new session layer or a new transport protocol, it achieves seamless handoff by following the middleware design philosophy [16], and by integrating the middleware with existing Internet services and applications.

As a result, USHA doesn't require any infrastructure modification and is scalable due to its middleware characteristics. This work is based on the fundamental assumption that handoff, either vertical or horizontal, only occurs on overlaid networks with multiple Internet access methods, which translates to zero waiting time in bringing up the target network interface when the handoff event occurs. Figure 1 shows the basic system architecture of USHA.

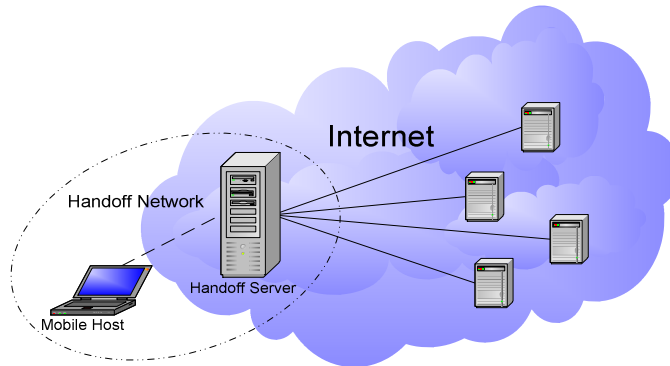


Figure 1: Universal Seamless Handoff Architecture

In USHA, the handoff network is composed of a handoff server (HS) and several mobile hosts (MH). Implementation wise, the handoff network can be configured using IP tunneling techniques such as IP encapsulation, with the handoff server functioning as the one end of the IP tunnel and the mobile host acting as the other end. An IP tunnel is then maintained between every MH and the HS, such that all application layer communications are “bound” to the tunnel interface instead of any of the actual physical interfaces. All data packets communicated through this IP tunnel are encapsulated and transmitted using the UDP protocol, which is a connectionless transport protocol.

This IP tunnel utilizes two virtual IP addresses and two fixed IP addresses, namely a virtual and a fixed IP address on both HS and MH. The fixed IP addresses are necessary for the MH to establish a physical connection to the HS. When the handoff event occurs and the physical connection from MH to HS changes, the handoff client is responsible for automatically switching the underlying physical connection of the virtual tunnel to the new interface. Since all the data packets are encapsulated and transmitted using the connectionless UDP protocol, the virtual tunnel is independent of the physical network connections, and there is no need to reset the tunnel after the handoff event. Therefore, the end-to-end TCP connection sessions, which are bound to the IP tunnel, are kept intact and remain transparent to the handoff events.

Contrasting to mobile IP based solution, USHA adapts to user mobility faster while maintaining better connectivity for established network sessions. For example, suppose a mobile user wishes to maintain an end-to-end network session while moving from an 802.11b network (network A) in the Computer Science Building, say, to a GPRS network (network B) while in transit, and finally arriving at an 802.11b capable destination (network C) in the Chemistry Building¹. If mobile IP is used to handle the handoff, the procedure will require a time consuming discovery/registration involving various foreign agents along the way. The discovery/registration latency is usually too large to achieve truly seamless handoff. USHA, on the other hand, maintains connection continuity without the latency associated with mobile IP. A simpler and faster handoff process in USHA ensures that all current communication sessions remain uninterrupted during handoff. Note that USHA can also serve to complement the mobile IP technology. While a mobile

¹ Assume GPRS enabled host, assume coverage of GPRS (network B) overlaps portions of 802.11b networks (network A, C).

host can use mobile IP to obtain a new physical address, it can still use USHA to take care the handoff process.

A USHA testbed was created to evaluate the performance of USHA under different handoff scenarios. The testbed consists of a mobile host and a handoff server, with both machines running the Linux operating system. The mobile host is a Pentium II 500MHz based laptop equipped with 802.11b/Bluetooth [17] wireless interfaces and 100Mbps wired connection, and the handoff server is a Pentium III 1.8GHz based desktop connecting to the Internet via a 100Mbps wired connection. The testbed uses OpenVPN [18] to realize IP tunneling and encapsulation, as well as *iptables* based NAT server [19] on the handoff server which masquerades all outgoing packets before they enter the Internet.

The first experiment tests the horizontal handoff delay from a dynamic IP (DHCP) address to a static IP address and vice versa within the same 802.11 wireless LAN. The dynamic IP address and the static IP address are addresses from two different subnets. The same 802.11b network interface is used for both addresses. A single FTP session is then activated from the mobile host to download a huge file from the Internet. The experiment is repeated for 5 times, and lasts approximately 120 seconds per run. The horizontal handoff event is triggered manually around 60 second into the experiment. Table 1 shows the experiment results.

Trial #	Duration (sec)	Delay (sec)	Throughput (KB/s)
1	123.6	2.6	550.16
2	122.4	2.5	555.56
3	124.5	2.6	546.18
4	121.6	2.7	559.21
5	126.9	2.4	535.86

(a)

Trial #	Duration (sec)	Delay (sec)	Throughput (KB/s)
1	121.9	0.9	557.83
2	120.9	1.1	562.45
3	124.5	1.0	546.18
4	124.6	1.1	545.75
5	122.2	1.1	556.46

(b)

Table 1: Horizontal handoff experiment results: (a) from static IP to dynamic IP, (b) from dynamic IP to static IP

According to the results in Table 1, the handoff delay from static IP to dynamic IP address is about 2.5 seconds, and the handoff delay from dynamic IP to static IP address is about a second. The difference is due to the fact that while switching to dynamic IP address, MH needs to search the network and negotiate with the DHCP server for a new IP address; whereas in the switch from dynamic IP to static IP address, no new address must be found and the handoff delay is much lower. Note that, since we collect the timestamp information from user space, the measured delay actually contains additional overhead introduced by the operating system.

The second experiment tests the vertical handoff delay from Bluetooth to 100Mbps Ethernet connection and vice versa. This handoff is termed “vertical” due to the need to migrate the existing connection to a different network technology. An FTP application is activated for 360 seconds for each trial, and the handoff is triggered manually at precisely 180 seconds into the experiment. Each experiment is then repeated for 5 times, and the results are shown in Table 2.

Trial #	Bluetooth Throughput (KB/s)	Delay (sec)	Wired Ethernet Throughput (KB/s)
1	44.16	0.9	336.35
2	46.96	0.9	332.58
3	45.32	0.7	339.99
4	44.48	0.6	346.51
5	49.56	0.7	312.56

(a)

Trial #	Wired Ethernet Throughput (KB/s)	Delay (sec)	Bluetooth Throughput (KB/s)
1	342.22	1.1	45.22
2	343.26	0.9	45.96
3	362.53	0.8	44.12
4	355.55	0.9	43.95
5	348.95	1.2	46.66

(b)

Table 2: Vertical handoff experiment results: (a) from Bluetooth connection to wired Ethernet connection, (b) from wired Ethernet connection to Bluetooth connection

In Table 2, the handoff delay is consistently around one second in either direction between Bluetooth and wired Ethernet connection, granted that the IP addresses for these two connections are pre-determined before the handoff occurrence. Again, the handoff delay might be an over-estimate since the timestamps are collected from the user space.

From the experiment results above, it is evident that USHA can handle both horizontal and vertical handoff seamlessly. The handoff delay is usually less than a second if the IP address of the target interface is pre-determined. The USHA solution makes use of existing, well established techniques (e.g. tunneling) and can be simply deployed without any mobile IP support. Moreover, due to the inherent features of middleware design, USHA is also capable of performing more sophisticated services, such as account management and access control, simply by tracking and differentiating the origin and the identity of IP tunnels. Connection security is also achievable via an encrypted IP tunnel.

Future work on USHA includes video streaming quality evaluation for additional USHA scenarios, especially since real-time applications like video streaming tend to be more sensitive to delay. Moreover, an intelligent USHA is also under development, which aims to provide USHA with the ability to automatically choose a “best” target interface when multiple options are simultaneously available. Decisions are based on several parameters including link capacity, energy consumption, current battery level and connection cost.

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