Practical Experiences with Wireless Integration using Mobile IPv6

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1. INTRODUCTION

World over, mobile Internet access has shown strong growth, fuelled by the increasing popularity of WiFi (802.11b-based WLANs), and the world-wide deployment of wide-area wireless networks such as GPRS and 3G. Multi-mode devices (e.g., WLAN-GPRS cards) are becoming increasingly affordable, and thus a growing number of mobile devices such as laptops, PDAs and handhelds are equipped to connect to multiple networks. Mobile IPv6 can play a key role in integrating different link-layer technologies, with the promise of enabling *transparent* mobility through use of a unified network layer. In this abstract, we summarize the extent to which, Mobile IPv6 protocol can be used to successfully migrate TCP connections during inter-network handoffs. The research is aimed at first:

- characterizing the latency components in a Mobile IPv6-based handoff,
- identifying protocol (TCP) performance problems during vertical handoffs using Mobile IPv6,
- explore the extent to which Mobile IPv6 protocol can hide differences of the disparate underlying link-layer technologies, and,
- demonstrate the efficacy of schemes that improve performance during vertical handoffs.

2. TEST ENVIRONMENT AND TOOLS

Our experimental setup consists of a Mobile IPv6-based loosely-coupled LAN-WLAN-GPRS testbed as shown in figure 1. In this testbed, the cellular GPRS network infrastructure currently in use is the Vodafone UK's production GPRS network. The WLAN access points (APs) are IEEE 802.11b APs located at different locations of the building.

The GPRS infrastructure comprises base stations (BSs) that are linked to the SGSN (Serving GPRS Support Node) which is then connected to a GGSN (Gateway GPRS Support node). In the current Vodafone configuration, both SGSN and GGSN node is co-located in a single CGSN (Combined GPRS Support Node). A well provisioned virtual private network (VPN) connects the Lab network to that of the Vodafone's backbone via an IPSec tunnel over the public Internet. A separate "operator-type" RADIUS server is provisioned to authenticate GPRS mobile users/terminals and also assign IP addresses.

For access to the wireless testbed, mobile nodes (e.g., laptops) connect to the local WLAN network and also simultaneously to GPRS via a Phone/PCCard modem. The mobile node's MIPv6 implementation is based on that developed by the MediaPoli project, chosen for its completeness and open source nature.

We brokered a semi-permanent IPv6 subnet from BTExact's IPv6 Network, which connects us to the 6BONE. Using the address space, we are able to allocate static IPv6 addresses to all our IPv6 enabled mobile nodes. A router in the lab acts an IPv6/IPv4 tunnel end-point to the BTExact's IPv6 network (shown in figure 1). This router is also an IPv6 access router (Home Agent) for the lab's fixed-internal IPv6-enabled network and also for internal WLANs. Routing in the Lab has been configured such that

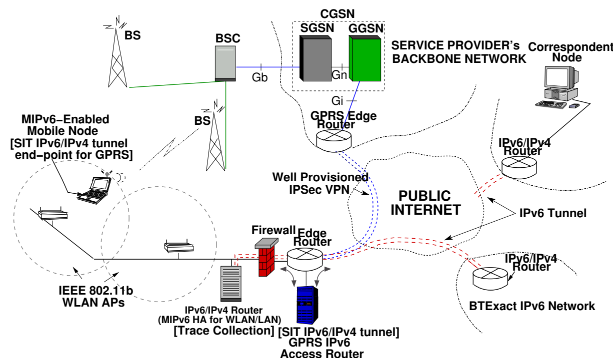

Figure 1: GPRS–WLAN–LAN Testbed.

all GPRS/WLAN user traffic going to and from mobile clients are allowed to pass through the internal router, enabling us to perform traffic monitoring.

Since the GPRS cellular network currently operates only on IPv4, we use a SIT (Simple Internet Translation) to tunnel all IPv6 packets as IPv4 packets between the mobile node and a machine providing IPv6-enabled access router functionality on behalf of the GPRS network. Ideally, the GGSN in the GPRS network would provide this functionality directly, but using the tunnel incurs only minor overhead.

All the characterization tests for GPRS-WLAN-LAN vertical handoffs were analysed using a version of `tcptrace` program updated (`tcptrace+`) to trace TCP connections for Mobile IPv6 handoffs.

3. EXPERIMENTAL EVALUATION

We investigated the extent to which Mobile IPv6 could be used to successfully migrate TCP connections during inter-network handoffs. From the handoff characterization process, we split the Mobile IPv6 handoff latency into three main components – detection time (t_d)(includes movement and any duplicate address detection time), configuration time (t_c), and registration time (t_r), each of which contribute to the overall handover latency [1].

We studied the effects of mobility on vertical handoffs, and have highlighted the challenges with IP mobility. Using the testbed, we have evaluated the impact layer-3 *hard* handoffs have on transport protocols such as TCP. Here, we summarize our practical experiences, a thorough description is available in the form of a separate technical report [1].

We conducted vertical handoffs between different networks – GPRS↔WLAN and GPRS↔LAN – using a multimode mobile device located in a WLAN hot-spot (and LAN) and also under GPRS coverage.

Figure 2 shows a typical TCP connection behaviour during a vertical handoff between GPRS↔WLAN. We find that the time

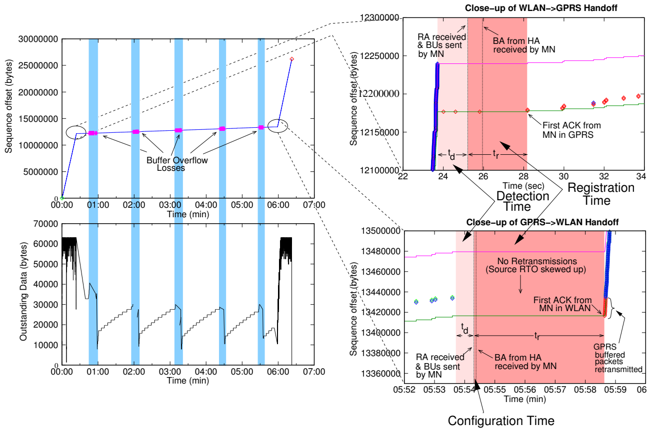

Figure 2: tcptrace+ of WLAN→GPRS→WLAN handoff.

to handoff from GPRS→WLAN and WLAN→GPRS to be high (approx. 5s). Consequently, TCP connections experience multiple time-outs before the handoff is complete. A number of factors contribute to such high handoff latency, but mainly the disparity in the link-layer characteristics between the two networks (see [1] for more information). [1] also gives mean latency of each handoff component in t_d, t_c, and t_r.

4. HANDOFF OPTIMISATIONS

Besides handover measurements, we also evaluated schemes for handoff optimisation specificallly for improving TCP performance. Here, we briefy discuss our practical experiences with these optimisations.

`Hard Handoff Optimisations:` We applied the following optimisation schemes to improve hard handoff performance:

- `Fast Router Advertisements (Fast RAs).` We used Fast RAs to improve handover performance, and have shown that reducing RA interval also reduces detection time during handoffs. However, we also observed that reducing RA interval to very low values (40ms-70ms) as that typically specified by the latest Mobile IPv6 draft leads to substantial overhead in GPRS (upto 25-50% of total bandwidth), and does not always guarantee significant improvement in mean detection times.
- `Client-based RA Caching.` RA caching is a technique to eliminate detection time during vertical handoffs. In this scheme, RAs are cached a *priori* by the mobile client, so that when the decision to handoff is taken, the detection time for RA lookup during handoff execution is eliminated, thereby improving handoff performance. We implemented the RA cache as a Linux 2.4 module, and have shown that the benefits of eliminating detection time ($t_d \sim 0$) during vertical handoffs is significant.
- `Smart Buffer Management using TCP Proxy.` We have shown that excess buffering due to long (or a large number of) TCP connections in the GPRS GGSN node can inflate the source TCP's RTT, and hence, skew the retransmission timer (RTO). This can prevent the source re-transmitting during handoff from GPRS→WLAN. Current GPRS networks offer excess buffering, and this can be prevented using smart buffer management. We used a TCP enhancing proxy that prevents the source from excessively buffering data, and have shown substantial improvement in registration times during handoffs.
- `Client-Assisted Binding Update Simulcast.` We observed that when handing off from WLAN→GPRS, the registration process of binding updates (BU) to the correspondent node would entail the high RTT of the GPRS link. BU simulcasting is a scheme to bicast BUs not only from GPRS, but also from other fast networks (e.g., WLAN/LAN) just before a client decides to handoff. We implemented BU simulcast as an extension to the MIPL Mobile IPv6 source code and have shown that it can further reduce registration times during *upward* vertical (WLAN→GPRS) handoffs.

`Layer-3 based Soft Handoffs:` In hard handoffs, the mobile device stops listening on one interface (or that network) and simultaneously *up* (start listening from) the other. As a result, packets that are already in-flight, to the previous network interface, unfortunately, are not read. These packets have to be retransmitted by the source, which leads to reduced performance.

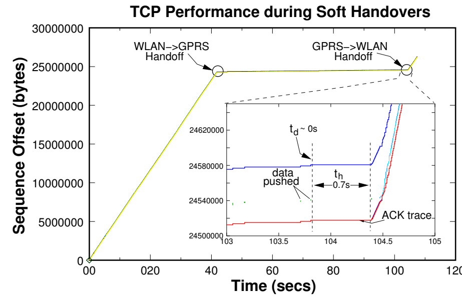

Figure 3: Exploiting Macro-diversity in (Soft) Handoffs.

Unlike hard handoffs, a better technique to handoff across coverage offered by networks in a wireless overlay can exploit the inherent macro-diversity available in order to make handoffs *soft* to help improve performance. We implemented the *soft* handoff scheme as a Linux module (along with RA caching) and figure 3 shows one such trace for TCP using soft handoffs with RA caching enabled. We have found TCP performance to dramatically improve with soft handoffs (and RA caching enabled) with only 0.7s required for the handoff than the one we have shown earlier (with hard handoff in figure 2). Traditionally, soft handoffs have been successfully exploited for link-layer handoffs in cellular networks.

These experimentations reveal the efficacy of the soft handover approach, which when applied with other (hard) handoff optimisation schemes as discussed earlier, improves TCP performance during vertical handoffs dramatically.

5. OPEN ISSUES FOR RESEARCH

There are many issues resulting from this research:

1. Can soft handoff approach applied at Layer 3 be used for high mobility environments? What quantitative benefits can we achieve using a similar approach even for real-time flows?
2. How can we have smooth handoffs (taking into account link bandwidth-delay product) while handing off from faster/fatter WLAN (or LAN) to slower/thinner GPRS?
3. In soft handoffs, can we prevent the source TCP from entering fast-restransmit mode (due to dupACKs generated by the mobile client) during handover from slow (GPRS) to fast networks (WLAN)?

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6. REFERENCES

[1] R. Chakravorty, P. Vidales, L. Patanapongpibul, K. Subramanian, I. Pratt and J. Crowcroft. "On Inter-network Handover Performance using Mobile IPv6". University of Cambridge Computer Laboratory– Technical Report, June 2003. `http://www.cl.cam.ac.uk/coms/publications.htm`

[2] P. Vidales, R. Chakravorty, L. Patanapongpibul. "Ubiquitous Networking in Heterogeneous Environments". in Proceedings of the *8th IEEE Mobile Multimedia Communications (IEEE MoMuC 2003)*, October 2003. (to appear)