Fast and Efficient IP Handover in IEEE 802.11 Wireless LANs

Ioanna Samprakou
Department of Computer Engineering and Informatics, University of Patras, Rion, Patra, Greece, & Atmel Hellas MMC S.A., Paleo Faliro, Athens, Greece

Christos J. Bouras
Department of Computer Engineering and Informatics, University of Patras, & Research Academic Computer Technology Institute Rion, Patra, Greece

Theodore Karoubalis
Atmel Hellas MMC S.A., Paleo Faliro, Athens, Greece

Abstract: This paper presents an effective and simple solution to the problem of Layer 3 (L3) handover in IEEE 802.11 wireless LANs (WLANs), so as to extend the IP mobility area of 802.11 wireless Stations (STAs). The IEEE 802.11f Inter-Access Point Protocol (IAPP), handles the Layer 2 (L2) mobility of STAs during L2 (intra-network) handovers, and offers IP connectivity via L2 specific methods. Instead of using a different protocol for the L3 mobility management of STAs, such as Mobile IP (MIP) [4] or a MIP-variant, the IAPP protocol is extended so as to also support the inter-network (L3) movements of 802.11 STAs. The proposed IAPP-based mechanism supports host mobility and offers substantial uninterrupted wireless IP-connectivity, even after L3 movements. The cornerstones of this mechanism are the zero-delay IP movement detection and the zero over-the-air IP signaling during IP handover establishment, which lead to seamless (very fast) and smooth IP handoffs. This fast IP-handoff method is especially suitable to 802.11 systems, as it has better performance than traditional MIP-based methods (shorter handover delays, near zero packet loss), while makes IP roaming transparent to the mobile STAs.
Keywords: IP mobility, IEEE 802.11 WLANs, IP handover, Fast handoff, tunneling.

1 Introduction

The growing requisition for user mobility has impelled the evolution of wireless networking technology over the recent years. A very significant issue in the area of wireless and mobile communications technology is the provision of constant wireless IP-connectivity to mobile nodes upon roaming. Today, the IEEE 802.1f Inter Access Point Protocol (IAPP) addresses L2 handovers (roaming between Access Points (APs) inside STA's Home Network), but not L3 handovers. Mobile IP, on the other hand, addresses roaming but not without considerable reconnection time (latency). For applications such as voice and video, this may be prohibitive. This paper presents a mechanism for fast and reliable L3 handover support in IEEE 802.11 environments, which extends WLAN roaming capabilities by offering uninterrupted service even to time critical applications due to its seamless and smooth handover. It is built on top of the 802.11f Inter Access Point Protocol (IAPP) [8] which is used for the L2 mobility management of STAs (fig.1- L2 Handover). *L3 handover* occurs when the network point-of-attachment of a mobile STA changes after an inter-network movement (inter-network or intra-foreign-network movement (fig.1- IP Handover)). In such cases the STA’s ongoing sessions are disrupted and IP-connectivity via its home IP address is lost.

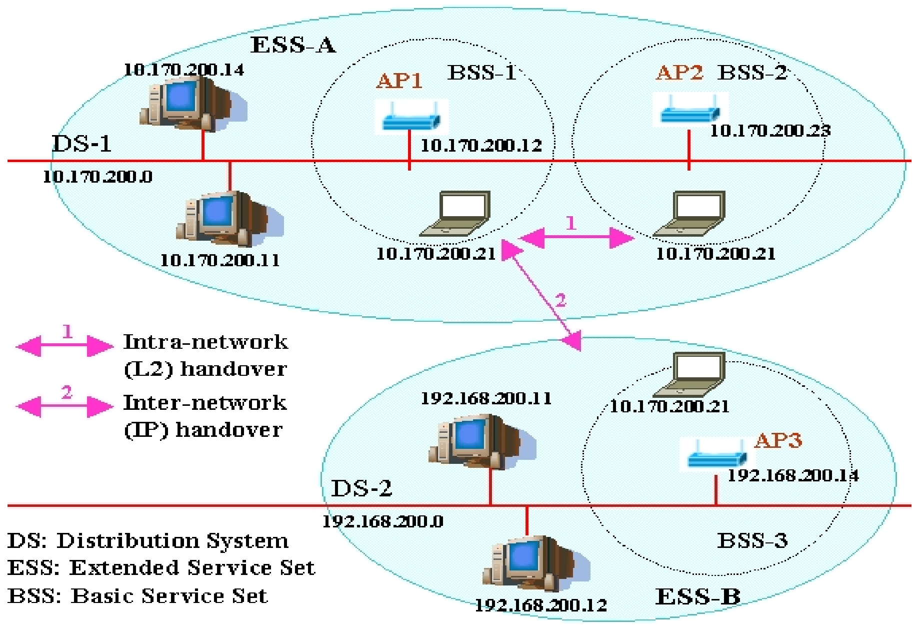

Figure 1 – Intra-network handover (IAPP Reassociation) & Inter-network handover

Our purpose is to support seamless and smooth L3 (IP) handoffs of STAs when roaming between APs of different IP networks, so as to maintain the active sessions as well as enable routing of IP datagrams to/from their current foreign location using their original IP address. As will be shown later in the test results, the proposed method quickly restores IP connectivity and successfully preserves the ongoing sessions, as the overall handover delay (L2 + L3) is insignificant, even for demanding and delay-sensitive applications. Mobile IP could be used to support IP (L3) mobility of STAs; however, this is not the most appropriate solution for 802.11 systems, as discussed later. Instead of using MIP to handle L3 handovers, the IAPP protocol is slightly extended with additional L3 functionality. The proposed mechanism comprises of new IAPP-based protocol sequences and advanced routing methods applied in the APs. It totally depends on the underlying Layer 2 (L2) technology (802.11) and results in shorter handover recovery periods, in a way which makes IP roaming transparent to the mobile nodes. The cornerstone of this mechanism is the zero-delay movement detection mechanism and the fact that there is no over-the-air protocol traffic for handover establishment, and therefore results in seamless and almost zero-loss IP handoffs.

2 Related Work

The recent literature provides a number of protocols and mechanisms proposed for IP mobility support (intra-domain and inter-domain) of wireless and mobile users. Most of these approaches are based on the Mobile IP, a mechanism developed for the network layer to support mobility. Several techniques have been proposed so as to optimize the MIP performance (long handover delays make MIP unable to preserve open IP sessions upon IP handovers), by either improving MIP handoff latency, or by optimizing MIP routing.

To make MIP handoffs more suitable for real-time and delay-sensitive applications (improve handoff latency), two new methods are proposed in [10]. In the *Pre-*

Registration (*Fast Handoff*) method, the STA is informed (assisted) that a L2 handoff is anticipated (L3 handoff is performed before completion of L2 handoff). The *Post-Registration* (*Proactive Handoff*) method acts analogously, however the handoff is performed between the two concerned FAs. Unfortunately, none of these methods can be applied in IEEE 802.11 systems: they are based on the fact that the APs involved in an STA's reassociation can "anticipate" the handover before it is actually performed, however the 802.11 APs become aware of an STA's movement only after real occurrence of a reassociation event at the new AP. More recent methods have been proposed to shorten the movement detection delay, applied either at the STA or at the APs. In the first case, the STA pre-caches the IP information needed to perform the IP movement detection, without depending on the MIP advertisements for this purpose. In the latter case, the APs are either pre-configured with information useful to perform movement detection for a newly connected STA, or obtain this information via periodic announces or other similar methods (centralized caching of the necessary information in each subnet).

Moreover, several MIP-based micro-mobility protocols have been proposed so as to improve the MIP performance (both handover latency and routing) during micro-mobility movements. Some of these approaches concern mobile-specific routing, like in Hawaii [11] and in Cellular IP [2]. Another proposal is intra-domain multicast-based architecture [1], which achieves efficient handover using standard multicast join/prune mechanisms. Other micro-mobility approaches, like Hierarchical MIP [7], are based on hierarchical topologies of FAs inside foreign networks. Hierarchical MIP can also support multiple levels of FAs [6]. All these approaches are based on typical MIP to handle the macro-mobility of STAs, however effectively reduce the handover time in micro-mobility cases.

3 L3 Handover Scheme

The proposed fast IP-handoff mechanism is built on top of IAPP, and gets triggered when the new AP receives an IEEE 802.11 Reassociation.Request [9]. The L3 handoff support protocol sequence is triggered when the receiving AP identifies an IP handover; otherwise, standard IAPP handles the L2 one. The IP movement detection identification is based on a small extension carried in the Reassociation.Request message: IP address of HAP, STA, and PAP. Thus the IP movement detection is carried out simultaneously to the L2 reassociation (zero IP movement detection latency). The STAs are identified at their foreign location via the new AP IP address; this is the Foreign Agent Care of Address (FACOA). For advanced routing, IP tunneling, Reverse Tunneling, Rule-based routing and Proxy-ing methods are implemented on the involved APs. Security is handled via 802.11 specific methods (802.11f IAPP).

The new packets (TCP) used upon the L3 handover are: Roam-Request/Response and Tunnel-Request/Response (figures 2, 3). They have the same format as the IAPP Move-Notify/Response packets with a small additional payload. The new protocol sequence involved in an *inter-network* IP handover is shown in figure 2, and figure 3 shows the phases of *intra-foreign-network* IP handover. Every AP acting as a HAP preserves a list, *RegisteredList*, of its registered STAs (currently away from HN), and every AP serving as a FA preserves a list, *VisitorList*, of each connected STA which has roamed from a foreign subnet. Each involved AP identifies its current role (New AP, Home AP or Previous AP) during a L3 handover, and performs the appropriate actions as opposed by the new protocol procedures. The new protocol procedures of our mechanism for each possible case of L3 handover are the following:

3.1 Movements between Home and Foreign Network (inter-network movements)

The STA reassociates to a new AP in a foreign network, while previously associated to its HAP (inside HN). Upon receipt of a Reassociation.request (case of L3 handover), the NAP communicates with the HAP, and a bi-directional HAP-NAP IP tunnel is then established. All STA's IP traffic is now supported by this tunnel, via advanced routing setup which has been performed at the two concerned APs (routing rules, routing tables, proxy arp functionality, etc). While connected to a foreign AP inside a FN, the STA IP sessions with correspondent hosts of the visited network are not forwarded via the tunnel to the HAP (no triangle routing).

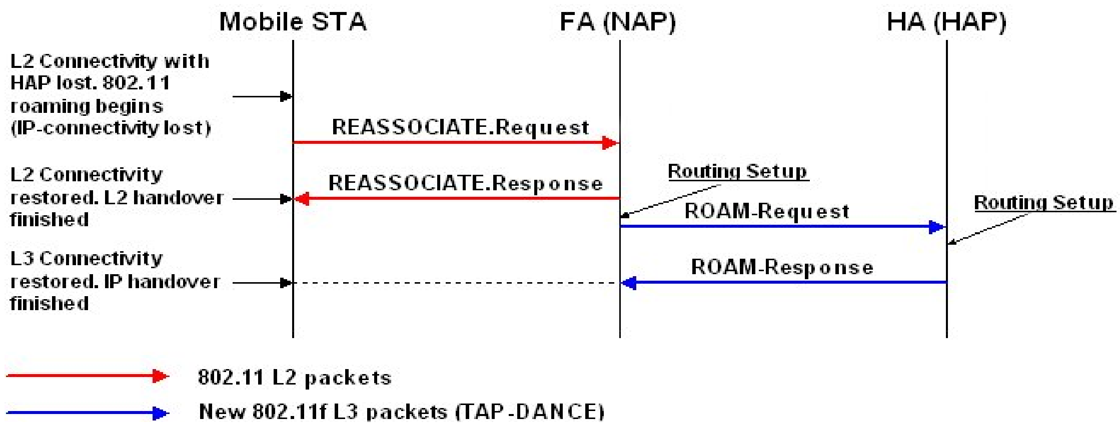

Figure 2 – Message sequence chart and actions performed upon an Inter-network movement

3.2 Movements between foreign networks (inter/intra-foreign-network movement)

The STA reassociates to a new foreign AP, while previously associated to another foreign AP. Upon reassociation, the NAP identifies a L3 handover. The protocol procedure consists of the same phases as in the inter-network movement, with an addition of a communication between the two concerned foreign APs and the establishment of a unidirectional tunnel between them. Via the temporary PAP➔NAP tunnel, any STA's remaining packets are forwarded from the PAP to the NAP. This operation aids in the quick recovery of the disrupted sessions, providing the means for low-loss and low-latency restoration of IP-connectivity. This tunnel is deleted after a small period of time.

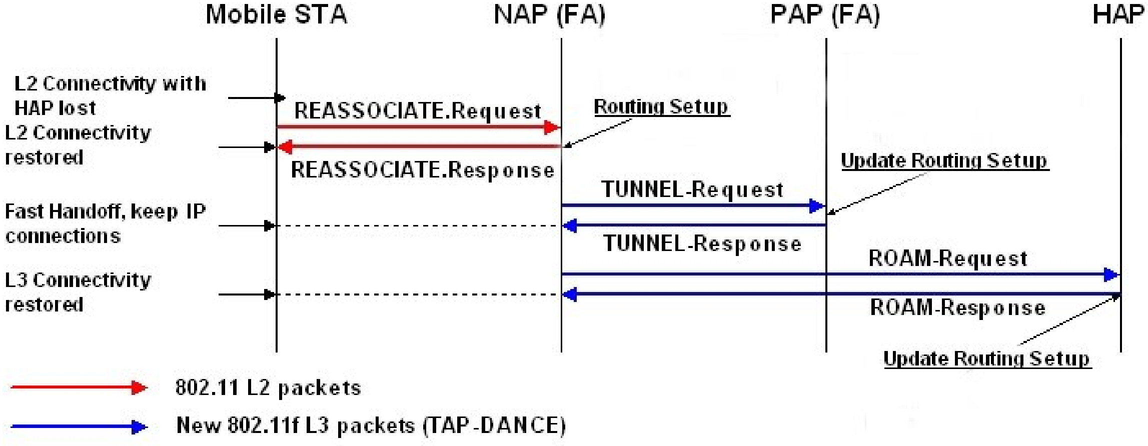

Figure 3 – Message sequence chart and actions performed after Inter-foreign-network movements

4 Performance of the IP-Handoff Mechanism

4.1 Why not use MIP - L3 handover analysis

There are significant reasons for not adopting a MIP-based method for IP mobility in 802.11 systems, concerning both MIP applicability on such systems, and performance. Firstly, MIP requires both the 802.11 STAs and APs to implement all MIP functionality (periodic protocol message exchange, routing, tunneling, etc); involvement of the STAs in the handover support is undesirable, as this would cause a significant degradation of their performance. Moreover, the MIP over-the-air signaling during IP handover poses further delay in the IP handoff setup period. Furthermore, a possible MIP deployment in 802.11 systems cannot make use of the MIP optimization techniques concerning handoff latency improvement ([5],[10]), for the reasons explained in Section 2.

The proposal presented in this paper is focused and heavily based on IEEE 802.11 technology. It considers APs with advance routing functionality, however the handoff support is performed in a way that it is transparent to STAs; no burden in their protocol stack. Only APs require a software update to allow efficient handover, and no additional device is required for caching or other purposes.

The IP handoff methods are applied together with the L2 ones: the L3 trigger (IP-handover process) is generated simultaneously to the L2 trigger (802.11 Reassociation event) at the new AP. The total L3 handover of the proposed mechanism is restricted to the 802.11 L2 handover and a round trip time with the HAP. The interruption time is only limited to the 802.11 L2 handover latency plus a signalization (only in the wired medium) comprising of 2 TCP packets. Therefore, the proposed method results in very fast IP handover recovery periods and low packet loss, which is verified by the experimental results.

This is accomplished using a far more simple and “light” mechanism than MIP, thus being more efficient for the 802.11 case from traditional MIP methods.

4.2 Experimental Results

The roaming and handover protocol presented here was implemented on the wireless router/Access Points based on Atmel's AT76C511 (IEEE 802.11). For testing purposes, the Atmel 802.11 VoIP phones and USB STAs were used as the mobile STAs. The STAs roamed between APs of different IP subnets, while having open IP sessions to one and more than one correspondent IP hosts in the Internet. The metrics measured are the average packet loss for different packet size and for different data rates, and the total IP handover latency (L2 plus L3 handover period) that took place until restoration of the ongoing IP sessions.

The effect of the aforementioned features of the proposed mechanism is the small total handover latency (IP connectivity restoration period), as shown in figure 4, and the small packet loss (fig. 5, currently no buffering at the APs). Classical MIP has handover latency > 1sec, while all the MIP optimization mechanisms have shown total handover latency > 300msec.

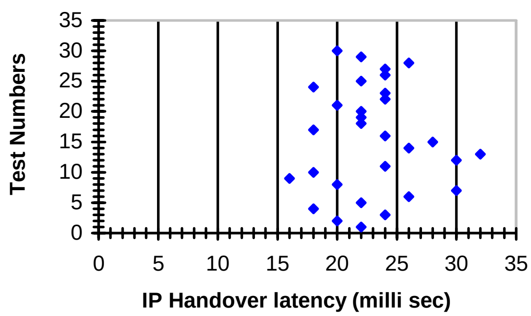

Figure 4 - Total IP Handover Latency out of 40 different tests

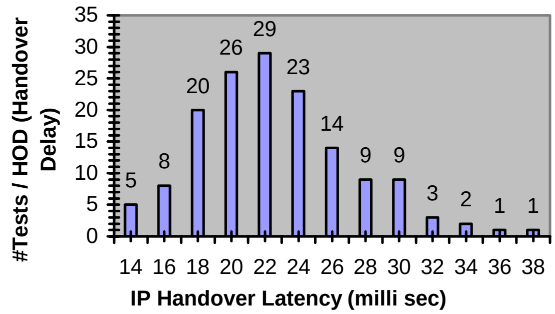

Figure 5 - Cumulative Frequency Density (150 different tests)

The variation in handover latency values from the different tests and the non-stable packet loss is due to the backbone traffic (of the Ethernet LAN and WLAN). Moreover, the packet loss shown in fig. 6 represents the sum of the number of packets which were not delivered to the STAs upon handover (totally lost packets) plus those IP packets which where delivered to the STAs but not answered immediately.

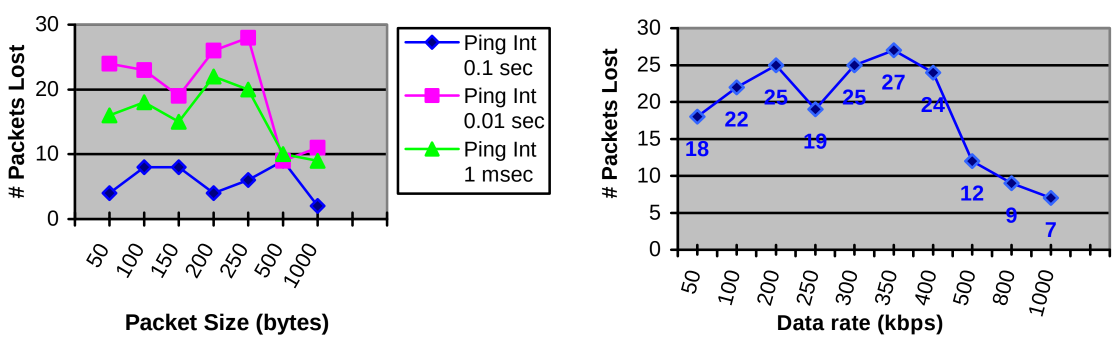

Figure 6 - Packet Loss vs. (a) packet size, (b) data rate

All tests were performed under normal (real) networking conditions, e.g. other traffic existed both over the air and over the Ethernet (10Mbps) medium. If the HAPs buffer incoming packets for the STA, there could be zero packet loss via our proposed method.

Next tests will be focused on measurements using advanced buffering mechanism on the APs during IP handovers of STAs.

5 Conclusions and Future Work

This paper presented a simple new mechanism, which supports unlimited STA mobility, by ensuring their constant IP-connectivity during any type of handover (IP or MAC layer). Our solution extends the current IAPP protocol and uses advanced routing mechanisms to effectively assist unbounded roaming of STAs. From experimental tests, it is proved that the proposed mechanism, applied only to the APs, achieves seamless (low-latency) and smooth (low-loss) handoffs, without aggravating the 802.11 STA devices.

A future consideration is to study ways to complement our mechanism with a routing optimization scheme specific to 802.11 environments, such as the use of a per ESS agent responsible for regional registrations of STAs inside foreign ESSs. Another issue is to extend the current IAPP-based RADIUS protocol [8] usage to support inter-network authentication and secure transfer of STA context information, as well as to support roaming-specific services in 802.11 WLANs.

6 References

[1] A. Helmy, M. Jaseemuddin, “Efficient Micro-Mobility using Intra-domain Multicast-based Mechanisms (M&M)”

[2] A.T. Campbell, J. Gomez, S. Sim, A. G. Valko, C-Y Wan, Z. Turanyi, “Cellular IP”, draft-ietf-mobileip-cellularip-00-txt, January 2000

[3] B. Aboba, Tim Moore, “A Model for Context Transfer in IEEE 802”, draft-aboba-context-802-00.txt, 15 October 2003

[4] C. Perkins, “IP Mobility Support”, RFC 3220, January 2002

[5] C.E. Perkins, and D.B. Johnson, “Route Optimization in Mobile IP”, draft-ietf-mobileip-optim-11.txt, September 2001

[6] Dynamics-HUT Mobile IP v0.6, “Dynamics - HUT Mobile IP Technical Document”, Helsinki University of Technology

[7] Eva Gustafsson, Annika Jonsson, Charles E. Perkins, “Mobile IP Regional Registration”, draft-ietf-mobileip-reg-tunnel-06.txt, March 2002

[8] IEEE 802.11f/D3, January 2002, “Recommended Practice for Multi-Vendor AP Interoperability via an Inter-Access Point Protocol Across Distribution Systems Supporting IEEE 802.11 Operation”

[9] IEEE Document P802.11/D6.1.97/5, “Wireless LAN, MAC and Physical Specifications”, June 1997

[10] K. El Malki, P. R. Calhoun, T. Hiller, J. Kempf, P. J. McCann, A. Singh, H. Soliman, S. Thalanany, “Low Latency Handoffs in Mobile IPv4”, draft-ietf-mobileip-lowlatency-handoffs-v4-03.txt, November 2001

[11] R. Ramjee, T. La Porta, S. Thuel, K. Varadhan, L. Salgarelli, “IP micro-mobility support using HAWAII”, draft-ietf-mobileip-hawaii-01.txt, July 2000