AN OPTIMIZED HANDOFF SCHEME FOR IP MOBILITY SUPPORT IN IEEE 802.11 WLANS

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Abstract This paper presents an 802.11-dependent IP mobility solution which accelerates the network reconfiguration phase after subnet handoffs and significantly reduces the IP handoff latency. The proposed fast IP handoff method offers the next generation WLAN applications such as Voice over WLANs (VoWLAN) complete freedom of movement without experiencing any connectivity problems. The performance results verify that this method outperforms other existing proposed IP mobility solutions in WLANs, in a way which introduces the lesser imperative amendments to the existing 802.11 wireless LAN framework.

Keywords: 802.11 wireless LANs, IAPP, fast handoff, IP mobility, IP connectivity

1. Introduction

One of the most challenging issues in the area of wireless communication systems is the provision of fast and efficient IP mobility support for 802.11 wireless clients. Next generation applications running on wireless networks pose an emerging need to both provide users with the ability to remain IP connected while being truly *mobile*, and to quickly restore (preserve) their connections during any kind of handoffs inside WLANs. Even though wireless LANs offer very high channel bandwidth, they show long network-layer handoff latency. This is a restraining factor for mobile clients using interactive multimedia applications such as voice over IP (VoIP) or video streaming. Important and useful services like employing VoIP over Wireless LANs (VoWLAN) are not yet realizable, as one of the most important challenges, the roaming latency (excessive latency and jitter, degraded voice quality), remains unsolved. New ways must, therefore, be examined for optimizing the time required to complete the inter-network BSS transitions of wireless clients.

Recent literature presents various methods to enable network routing to and from a mobile hosts alternate points of attachment as it moves around in wireless LANs. These methods may differ in their assumptions about the characteristics of the underlying Layer 2 technology, and in the approach adopted to solve the problem. A very interesting work on the subject is the handoff scheme presented in [4] (*Daedalus* project): it makes use of *multicasting* and *buffering* mechanisms to reduce the IP handoff latency and obliterate data loss during handoffs. However, it is based on the anticipation of an impeding handoff, and assumes that the handoff is triggered by the mobile clients software. An enhancement of this method is proposed in [6], with the use of a *Domain Foreign Agent* responsible for multicasting information across multiple cells. A different method is the fast handoff scheme called *Neighbor Casting* [5], which tries to reduce the Mobile IP protocol traffic exchanged over the wireless network during handoffs. For this reason, it provides the access points (mobility agents) with a neighbors map. Unfortunately, it is also based on link-layer triggers for a forecasted handoff. A very interesting approach is presented in [11] (*MosquitoNet* project). The general idea is that while residing in a foreign network, the mobile host functions as a foreign agent (FA) of its own, and utilizes advanced routing to receive/transmit IP data from inside the visited subnet. For this purpose, it first obtains a temporary IP address from the new network. While this method eliminates the handoff delay introduced during the agent detection phase, it poses a significant delay for IP address acquisition. A more recent work on the subject presented in [1], makes a very interesting proposal which significantly shortens the total Mobile IP handoff latency in cases of *hard* and *forward* 802.11 handoffs. It makes use of a timer-driven software *probing* technique to facilitate the detection of the occurrence of an 802.11 handoff, and a Mobile IP advertisement caching and *replay* proxy to quickly discover new mobile agents using only unicast communication. So far, it results in the smallest observed Mobile

IP handoff delay during network mobility in 802.11 wireless networks (in the order of 100ms). In order to support fast and seamless handoffs by reducing the delay and data loss during IP handoffs, [7] proposes the following methods: (a) a *Pre-registration* method, which enables the mobile host to communicate with the new foreign agent in the notification of an upcoming handoff, while still attached to its home agent (HA), and (b) a *Post-registration* method, which is based on link-layer triggers for tunnel establishment between the two concerned mobile agents, so as to allow the mobile host to continue being served by its home agent, even when attached to the foreign agent. A similar approach is proposed in [10], using a proactive method in which the foreign agent assists the mobile node to perform a handoff.

The rest of the paper is organized as follows: Section 2 describes the IP handoff problem in WLANs and discusses the applicability limitations of the most related mobility solutions in 802.11 infrastructures. In section 3, we present the handoff optimization contribution of the proposed method along with description of the mechanism. Section 4 follows with the performance results of our method, while section 5 concludes the paper and presents our future work on the subject.

2. The proposed fast handoff scheme

2.1 Handoff latency optimization

The proposed handoff method is completely applicable to 802.11 infrastructure wireless LANs, as it is not based on any ability to forecast imminent link-layer handoffs; in particular, it exploits the 802.11-core functionality to achieve fast and smooth IP handoffs, optimizing existing methods network layer handoff delay. More specifically, lets first examine the individual delay parts involved in Mobile IP handoffs. The overall delay introduced until successful network handover establishment comprises of the following latency phases:

- The delay from real occurrence of an 802.11 handoff, until its detection by the IP mobility entities (either at the Mobile Nodes or at the new access point)

- The intermediate time from the 802.11 handoff event detection, to the first Mobile IP message (MIP advertisement) from the new mobile agent

- The duration of a clients registration with the new foreign access point (foreign agent), after receipt of the first MIP advertisement

- The delay introduced during the communication between the home AP and the foreign AP for tunnel setup, after successful registration of the client to its foreign agent (AP)

The Mobile IP requires clients running the Mobile IP software, which is a considerable addition to their networking protocol stack. Moreover, the handoff procedure of Mobile IP involves both wired and wireless communications; over-the-air protocol traffic is introduced during the IP handoff establishment phase.

The method presented here accelerates the total IP handoff procedure, by completely eliminating the first three delay components. The key features are that:

- the IP mobility management is a responsibility of the 802.11 access points only. There is no mobile nodes involvement, and the total network layer handoff is transparent to the wireless clients, and
- no new protocol is used. It makes use and slightly extends the existing 802.11f IAPP for communication between the home AP and the foreign AP. Thus, no extra wireless traffic is introduced for IP handoff support reasons.

Only a minor software change is required by the IP roaming enabled clients for this method to be operational. This add-on serves for the APs to perform the necessary movement detection, so as to recognize an IP handoff in case of subnet movements.

2.2 Description of the IP handoff mechanism

This new 802.11-based fast IP handoff protocol complements the IEEE 802.11f IAPP in offering support for inter-network movements in WLANs. This method resembles the well known Mobile IP *routing* mechanisms; however, nor it is an additional network layer protocol, neither does it require support by both APs and wireless 802.11 clients. It is based on a totally different concept which solves the IP handoff problem in an 802.11f-compliant way. This is the reason why the proposed mechanisms leads to extremely small IP-reconnection delays of $<$60ms and very low packet loss, even without the use of any *buffering* or *data replaying* mechanisms (future consideration).

More specifically, it acts upon link-layer handoffs to perform the specific IP configuration procedure necessary to support the network handoff of mobile nodes. It considers APs also serving as mobility agents, meaning that the APs are responsible for the management and provision of IP mobility support to their associated stations. Every station powering up inside a BSS is assigned a Home Agent (HA). The HA is the AP to which a station is last associated as long as it remains inside its Home Network. A HA provides mobility services (routing of their IP datagrams using advanced routing mechanisms) to any of its stations, which have currently roamed to foreign subnets. The AP which provides wireless services to stations coming from different subnets is called a Foreign Agent, and is also responsible for offering IP connectivity to any visiting foreign station. This method provides advanced mobility services to wireless IP hosts, which are using a *static* IP address (globally valid, which may be pre-configured or dynamically obtained via e.g. DHCP).

The movement detection phase is carried out by the new AP (FA) immediately upon receiving a L2 trigger by the reassociating foreign mobile node. This phase requires that certain location specific information is provided to the FA by the newly connected client, using the existing 802.11b wireless protocol frames. This proprietary networking information is the only extension added to the clients software for this proposals mobility purposes; no changes in the protocol stack of the 802.11 clients, and no extra over-the air AP-MN protocol traffic during handover establishment.

After determination of a network handover (together with 802.11 reassociation), the two involved APs (the FA and the HA), carry out a fast notify/response transaction comprising of two TCP/IP 802.11f formatted packets. After completion of this inter-AP communication, the mobile client is able to restart transmitting/receiving packets using its original IP address, while connected to the FA inside the foreign network. Unlike the Mobile IP agent discovery/solicitation phase (movement detection), which includes wireless MIP protocol traffic to be exchanged between the MN-AP ***after*** completion of the link-layer handoff, no additional delays are imposed during the proposed handoff procedure.

Integrating this IP mobility support entity into the 802.11 APs, the total service interruption delay during which a client cannot receive IP packets is minimized to the link-layer handoff latency plus one TCP/IP round-trip time. The whole concept is based on the aspect that specifically for the case of wireless environments where the underlying technology is the IEEE 802.11, the key in achieving seamless (fast) and smooth (low-loss) IP handoffs is to provide an *802.11-dependent* solution. Due to the nature and the limitations of this L2 technology as discussed in section 2, link-layer independent solutions such as the Mobile IP and its variants cannot accomplish performance results (short delays, low jitter, low loss) tolerable by real-time and demanding applications.

No additional network infrastructure is used in this method. The only participants are the previous and new APs (the Home Agent and the

Foreign Agent) involved in a stations handover. Therefore, the proposed solution effectively combines simplicity with desirable performance.

3. Performance measurements

3.1 Test environment

The proposed fast handoff mechanism has been implemented on the wireless router/Access Points based on Atmel's AT76C511 (IEEE 802.11), with wired interface configures at 100Mbps and wireless interface configures at 11Mbps. The mobile clients used in our testing are laptop computers (Pentium IV) which uses PCMCIA Atmels wireless network interface cards. Furthermore, Atmel 802.11 VoIP phones were also used as mobile nodes running real time phone conversations during subnet movements. The mobile clients 802.11b driver has been slightly modified to provide transport of the necessary network-related information during handoffs. The correspondent hosts running open IP sessions with the mobile clients are desktop PCs (Linux) residing somewhere in the Internet.

Three APs participated in the tests, each of them residing to a different IP subnet (Ethernet) from the other two. The three subnets were: 10.170.200.0, 10.170.255.0 and 10.170.254.0. The performance metrics during the tests were (a) the total handoff latency (link-layer plus network-layer handoff delay) until restoration of the ongoing sessions, and (b) the packet loss. Two different movement scenarios were examined: (1) handoff between the home and foreign agent, and (2) handoff between two foreign subnets.

3.2 Performance results

In the first test, a wireless station (laptop) powered up inside subnet 10.170.255.0 and obtained a valid IP: 10.170.255.101. While attached to its home agent (10.170.255.100), it launches an ICMP session with a remote IP host (Linux pc: 150.140.141.155). Upon roaming to an AP (10.170.254.100) of an adjacent foreign subnet, we measured the time that passed from the last ICMP packet received via the home agent to the time the first ICMP packet was received via the foreign agent, and the overall packet loss for different packet size. The histogram out of the total handoff latency measurements is shown in Figure 1:

What is observed is a very small *total* handover latency (802.11 handoff delay plus IP connectivity restoration period) during intra-network movements between the home agent and the foreign agent. This time includes the link-layer handoff period, which takes about 5-20msec in av-

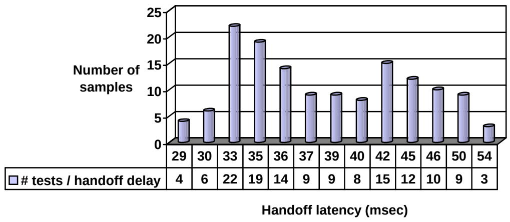

Figure 1. Cumulative Frequency Density of total handoff period (140 replications of test 1)

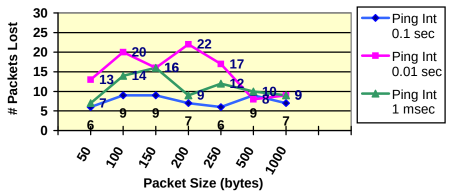

Figure 2. Packet Loss during a ping session (Test 1)

erage to complete, for the case of laptop stations (running windows) and 511 APs. The mobile clients regain IP connectivity after a maximum of 54msec, in worst case. A latency of 29msec was measured in the best case. The variation in handover latency values from the different tests is due to the backbone traffic (Ethernet LAN & wireless LAN). All tests were performed under normal (real) networking conditions, e.g. other traffic existed both over the air and over the Ethernet medium.

As soon as the clients becomes IP connected again with the assistance of its home and foreign agent, there is a TCP adjustment period until its sessions are fully restored (update of ARP tables for the remote hosts, etc). Using advanced routing techniques, the IP mobility entity of the AP takes the necessary actions for the client to quickly obtain the TCP specific information of its previous sessions. This assists in small IP packet loss during the handover, as shown in Figure 2:

The maximum number of packet loss is 22 packets, during a ping (ICMP) session with ping interval of 0.01sec. The minimum number is 6 packets, during a ping session which has ping interval of 0.1sec. The test results show that the packet loss is very small, even for high-demanding IP sessions. The non-stable packet loss is again due to the backbone traffic and the non-ideal networking conditions in general. The amount of packets appearing in the graphs includes those IP packets that reached the station right after the handover (IP connectivity already restored), but were *not answered* by the client. This is due to the transitional delay until the mobile IP host updates its ARP table after having moved to a foreign IP subnet. These packets were successfully delivered to the roaming stations but could not be replied, however, not due to the IP connectivity gap caused during the handover.

The second test was carried out using two VoIP phones. The phones first associate to an AP inside subnet 10.170.255.0. After successful 802.11 association and acquisition of a valid IP address, they initiated a phone conversation (Voice over WLAN). While in the middle of the voice call, one of the phones made a subnet move and connected to an AP inside subnet 10.170.254.0. What was observed is the *continuousness* of the call without being dropped or even disrupted. In fact, the interruption due to the IP handover was so short, that it was not even realized by the two counterparts who were communicating via the phones. This is due to the very short total interruption interval, which is far below the upper threshold of the 82msec in order for a discontinuation in VoIP calls not to be observed. In case there is an interruption interval much greater than 82msec—a common situation when using other IP mobility solutions—a VoIP call will be cut off.

In a different movement scenario, a wireless IP host again associated to a home agent inside subnet 10.170.255.0, and obtained a valid IP address. After roaming to a foreign agent (10.170.254.1), it launches an ICMP session towards the remote IP host (150.140.141.155). After a while, it roams towards an AP (new foreign agent) of subnet 10.170.200.0. This is a movement between two different foreign agents. In this case, the IP mobility entity involves communication between the new foreign agent and the home agent for quick establishment of the necessary routing setup, and a second communication between the home agent and the old foreign agent for disabling the clients specific previous routing setup. During the IP handoff, we again measure the IP session restoration delay as well as the total packet loss incurred during the movement. The histogram of the observed total handoff latency measurements is shown in Figure 3.

Regarding the results of the third test, we observe a small increase of 10–15msec in average, compared to the results in the cases of handover between the home and foreign agent (first test). This delay is due to the time needed for the home agent to disable the previous routing settings (bindings towards the previous FACOA of the MNs), until it starts forwarding MNs packets to its new foreign AP, based on the new routing setup (new routing entries, etc). Again, the IP-connectivity restoration period is small enough (<60ms) in order for the APs to effectively preserve even the most demanding applications of 802.11 wireless clients.

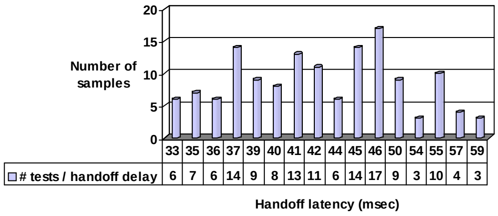

Figure 3. Cumulative Frequency Density of total handoff period (140 replications of test 2)

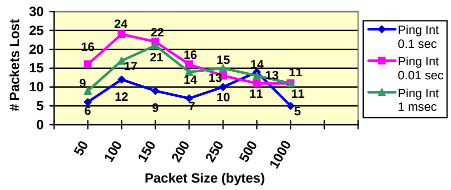

Figure 4. Packet Loss during a ping session (Test 3)

Concerning the packet loss, again, in case of a inter-foreign network movement, the total amount of packets lost is increased. This is due to the fact that some packets which crossed the HA escaped via the previous HA-FA routing path, and remained at the previous foreign AP (dropped). This problem can be effectively solved via temporary buffering at the HAs.

4. Conclusions and future work

Research in IP mobility support and handoff optimization is driven by the need to support next generation applications running upon wireless links. Real-time and demanding applications such as VoIP calls should be preserved even in the event of a subnet roaming, while the experienced performance degradation must be insignificant and not even noticeable to the client. Running the proposed mobility solution on the 802.11 APs, the wireless mobile hosts utilizing VoIP and other multimedia applications are freely moving around between neighboring subnets, using their home address, without experiencing any service interruption and without even realizing the IP handoff. This method is fully applicable to the 802.11 hard handoffs, works on the existing 802.11 framework as it is 802.11f compliant, and adds no extra protocol traffic. It is applied only to the APs, and achieves seamless (low-latency) and smooth (low-loss) handoffs, without aggravating the 802.11 clients.

Next tests will be focused on measurements using advanced buffering mechanism on the APs for the IP roaming-enabled stations. Furthermore, a future consideration is to study ways to extend the current IAPP-based RADIUS protocol usage to support inter-network authentication and secure transfer of STA context information, as well as to support roaming-specific (Context Transfer such as QoS information, IPsec, etc.) services in 802.11 WLANs.

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